DEPARTMENT OF THE INTERIOR

J C Branner

BULLETINS

no. 23

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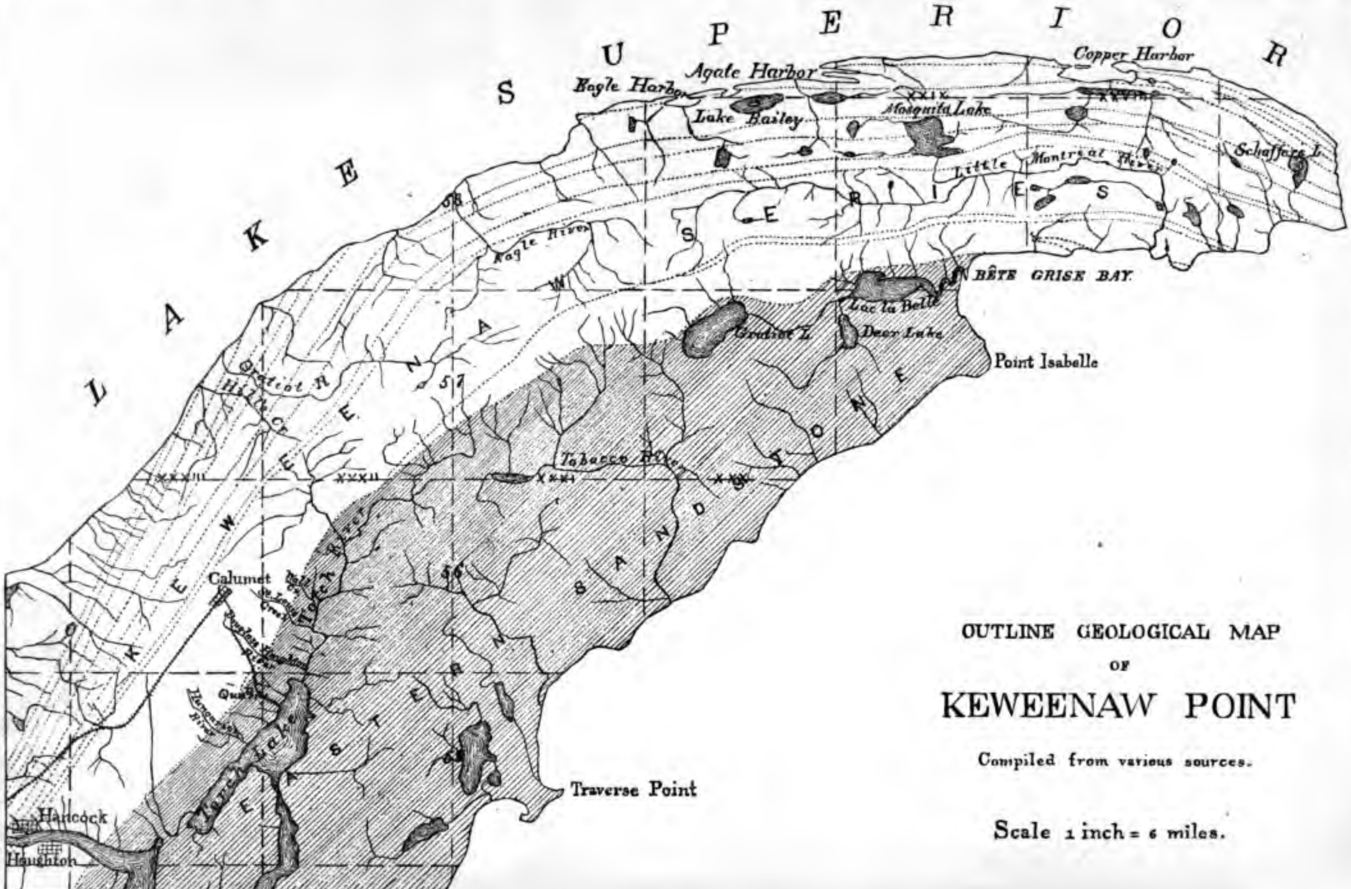

OUTLINE GEOLOGICAL MAP

OF

KEWEENAW POINT

Compiled from various sources.

Scale 1 inch = 6 miles.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

OBSERVATIONS

ON THE

JUNCTION BETWEEN THE EASTERN SANDSTONE

AND THE

KEWEENAW SERIES

ON

KEWEENAW POINT, LAKE SUPERIOR

BY

R. D. IRVING and T. C. CHAMBERLIN

23

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
Madison, Wis., February 15, 1885.

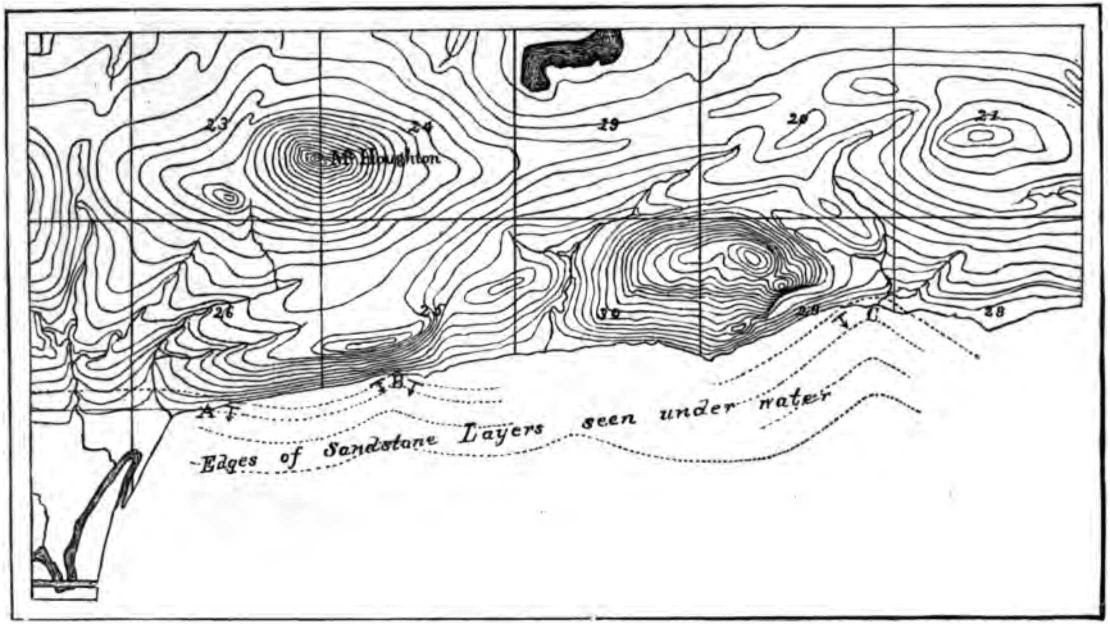
SIR: I have the honor to transmit herewith for publication as a Bulletin of the Survey a paper embodying the results of certain studies in Keweenaw Point geology made conjointly by Professor T. C. Chamberlin and myself.

The accompanying plates, except so far as they are reproductions of photographs, were drawn by Assistant Geologist W. N. Merriam.

I am, sir, very respectfully, yours,

R. D. IRVING,
United States Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.



MAP OF NORTH SHORE OF BÊTE GRISE BAY, KEWEENAW POINT.

Scale: 1 inch=1 mile. Contours, 30 ft. vertical distance.

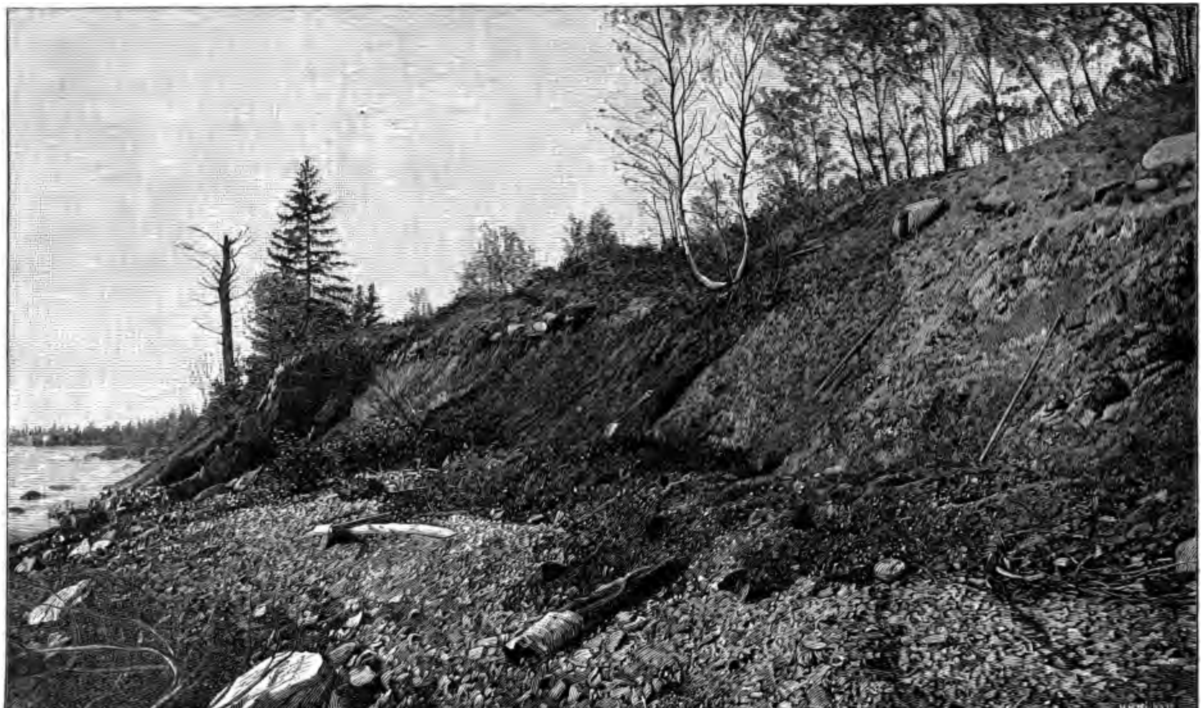
obliged to pass by is that of the exact nature of the structural details at the contact line between the Keweenaw Series and the so-called Eastern Sandstone. This contact line one of us had already examined sufficiently to satisfy himself of the general relations of the two formations concerned, but he had not been able to go further than this. Recently, however, the opportunity has offered for us to make together some additional observations on this line of contact, with results that have proved to be of so conclusive a nature that we think it well to publish them in the form of a bulletin.

In what follows the several places at which this junction has been studied by us are taken up in order from east to west. Preceding our own descriptions of each one of these points, we give the descriptions of others, so far as we are acquainted with them. Following these detailed descriptions, we then give an account and a discussion of the various views which have been held with regard to the relations of the two formations concerned, and then close with our own conclusions on this subject, as also in general upon the origin of the phenomena observed along the contact line.

BÊTE GRISE BAY.

As often described heretofore, Keweenaw Point consists of two portions, sharply separated topographically: an elevated ridgy portion, and a low-lying flat portion. The course of the ridge portion, beginning at Portage Lake, is at first northeastward; but, as it is followed farther eastward, this course is soon changed into an easterly one, and this again, at the easternmost extremity, into a southeasterly one. To the south and southeast of this crescentic ridge, which is made up of the beds of the Keweenaw Series, lies the relatively low and flat expanse underlain by the Eastern Sandstone. The junction line between these two formations is usually plainly marked in the topography. This is particularly the case towards the northeast, in the vicinity of Gratiot Lake, Lac la Belle and Bête Grise Bay. In the neighborhood of Torch Lake and Torch River the descent from the ridge to the lowland is less abrupt. The relative positions of these two portions of Keweenaw Point and the course of the junction-line of the two formations which underlie them respectively will be best understood from the outline map of Plate I, which is reduced from the colored map compiled from various sources and published in Volume V of the Monographs of the United States Geological Survey.

An inspection of this map will show that, at the eastern end of Keweenaw Point, the ridgy portion occupied by the Keweenaw Series extends some twelve miles farther east than the lowland portion. The rectangular bay thus formed where the lowland terminates is known as Bête Grise Bay. The northern shore of this bay, for some four miles eastward from its western extremity, lies very close to the junction



JUNCTION OF EASTERN SANDSTONE AND KEWEENAWAN MELAPHYR BÊTE GRISE BAY, KEWEENAW POINT

[From a photograph.]

between the Eastern Sandstone and the Keweenawan rocks, being at times ... short distance to the south of this ...

between the Eastern Sandstone and the Keweenawan rocks, being at times slightly to the north and again a short distance to the south of this junction. The topography of the neighborhood of this portion of the bay is indicated on Plate II, which is based upon a tracing furnished by the United States Lake Survey, from a manuscript map in their office. The contour lines stand at 30 feet vertical distance.

On account of their easy accessibility by boat, and also because of the appearances presented, the exposures of the Keweenawan traps and the Eastern Sandstone about this bay have attracted the attention of geologists from quite an early date. The following quotations include all the direct references to this place, as far as the Eastern Sandstone is concerned, that we have been able to gather, after having looked through most of the works in which any such references could be expected. So far as we have been able, we have arranged these quotations in the order of the times when the examinations were made upon which they are based. It has not, however, always been possible to ascertain the exact date from the publications cited. The name which precedes each quotation is that of the author; the date immediately following is that at which the examination was made; after which are given the titles of the works and their dates of publication.

C. T. Jackson, 1848. (Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in Michigan. Senate Documents, Thirty-first Congress, first session, 1849, Vol. 3, No. 1, p. 442.) "We visited next the mouth of Little Montreal river, and examined the rocks for some distance up that stream. This river falls into the lake over ledges of trap rocks, by a succession of leaps—the aggregate height of these falls being about 40 feet. Further up the stream, there are other minor falls and rapids. The rocks are hard and compact trap rocks, but slightly vesicular. No copper veins are found at this place, or any mineral of interest.

"Continuing our voyage to Lac la Belle, we noticed a peculiar breccia of porphyry and trap rock, which, at first sight, would be mistaken for conglomerate rock. It contains a large mixture of seams of leonhardite, some of which is of a bright red color, from peroxide of iron. Further towards Lac la Belle, we came to nearly vertical strata of sandstone, the dip being NE. 85°. The range of the outcrop, according to Mr. Foster's observation with a prismatic compass, is N. 70° W."[1]

C. T. Jackson, 1848. (Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in Michigan. Senate Documents, Thirty-first Congress, first session, 1849, Vol. 3, No. 1, p. 451.) "September 5. Rowed against a strong head wind to Jasper point, where we were forced to land on account of the violence of the wind and swell of the lake. Observed at this place (near Jasper point) a dike of brown trap rock, cutting through the porphyritic variety, and thus proving the more recent origin of the brown trap, as I had previously ascertained at other places.

"The wind abating, we set out again in the afternoon and ran round the curve of the bay to near the entrance of Lac la Belle, and then stood for Keweenaw bay,

[1] We are not certain whether this refers to the easternmost of the three places at which the sandstone is exposed on the coast of Bête Grise Bay, which we did not reach (the one marked C on the map of Plate II), or to the middle one (marked B). The latter we have examined, as indicated beyond, but saw no such northerly dip as 85°. However this may be, there is certainly no place where such a bearing and dip hold for any distance, and we doubt its occurrence at any point.

leaving the other boat to visit Lac la Belle. * * * In following the course of the lake near Lac la Belle, I examined the rocks very particularly at their points of junction. The gray sandstone is observed in large blocks suitable for building, though not very compact or strong. The strata in place dip southeast 20°.[1] At the junction of this rock with the trap, and for half a mile north, the rock is brecciated, and a large castle-like outline [outlier] projects into the lake, so that we could run behind it in our boat. The belt of trap in the rear of this breccia is only 40 feet wide. The breccia is seen near the landing of the Clinton Company. During a short stop at the Clinton Company's wharf, I took an observation for time, and then set out on our voyage again. A band of trap a quarter of a mile wide was seen between the breccia and gray sandstone. A curious crescentic band of white sandstone was seen in this bay, beneath the water, and about half a mile from the shore. After passing a band of trap we came again to red sandstone strata, dipping to the south 30°.[2] Point Isabelle is a variegated sandstone cliff, consisting of alternate layers of red, gray, and mottled sandstone in nearly horizontal strata. Orbicular white spots, with nuclei of black, occur abundantly in the red sandstone, and appear to be concretions. Nodules and beds of red chalk are abundant in the gray sandstone or between their strata. This cliff is very beautiful, the top being gray sandstone, the middle red, and the base striped alternately with gray and red. The cliff is perpendicular, affording no landing place: its height is 40 feet. The whole of this sandstone coast is abruptly precipitous, and it is dangerous for boats to be caught by high winds on such a lee shore. The wind was in such a direction that I was enabled to sail quite near the rocks on the wind, so as to observe them leisurely as we ran along the coast."

J. W. Foster, 1848. (Letter to Dr. C. T. Jackson, United States Geologist, dated mouth of Menomonie River, September 28, 1848. Senate Documents, Thirtieth Congress, second session, 1848, Vol. 2, No. 2, p. 160.) "At Bête-du-Gris Bay, where the Bohemian range approaches the lake, we found that the trap, instead of being forced through the layer of sandstone, as observed in the northern slope of Keweenaw point, was protruded through a fissure in the sandstone, tilting it up and causing an anticlinal axis. The bearing of the stratified rocks here is found to be northeast, and the dip 76° to the southeast. A few miles further south the rock becomes nearly horizontal, and between that point and L'Ance it acquires a series of gentle undulations, so that little importance was attached to any of our observations, as to its bearing and inclination."[3]

J. W. Foster, 1848. (Letter to Dr. C. T. Jackson, United States Geologist, dated August 25, 1849, Senate Documents, Thirty-first Congress, first session, 1849, Vol. 3, No. 1, p. 767.) "Two miles above Sibley's landing, sandstone composed of white and red bands is observed, dipping easterly $<$ 85°. In the bottom of the bay it is exposed admirably, and can be examined to advantage when the water is calm. It exhibits a series of curves, conforming apparently to the Bohemian range. I was exceedingly anxious to trace out the bearings of these curves, but the party would not submit to the detention."[4]

J. W. Foster, 1849. (Report to Dr. C. T. Jackson, United States Geologist, Senate Documents, Thirty-first Congress, first session, 1849, Vol. 3, No. 1, p. 782.) "On the south side of Keweenaw Point (section 27, township 58, range 28, near the meander-

[1] We take this to refer to sandstone exposure C of Plate II.

[2] We take this to refer to exposure A of Plate II.

[3] We understand this to be a general account of the conditions on the north side of Bête Grise Bay, rather than a reference to any one locality. Certainly, however, a bearing of the sandstone to the northeast and a dip of 76° southeast are not general conditions, but purely local ones, holding at most for a few feet only, since the sandstone, as shown later, presents many different bearings and dips along the contact.

[4] This evidently refers to the same place as described by Jackson in a preceding quotation.

post between sections 27 and 28), above Bête du Gris Bay, sandstone is to be seen, bearing N. 22½° E., and dipping southerly, or away from the trap, for a distance of nearly three-fourths of a mile. It is white and granular, destitute of pebbles, and nearly so of iron.[1]

"On section 36, township 58, range 29, it is again seen on the shore of the lake for the sixth of a mile, abutting against a bed of brick-red conglomerate. Course N. 45° E., dip 76° SE.°.[2]

"This conglomerate band, about twenty-five feet thick, is identical in lithological characters with those on the northern slope of the axis, and laps on the chlorite rock. The same is seen on the Lac la Belle location, but beyond that point we have not been able to trace it. The sandstone here consists of alternating bands of red and yellowish silex, with no trace of lime.

"In the bottom of the bay, at this point, when the water is calm, the buff and red bands can be seen describing immense curves, parallel to the direction of the Bohemian range of mountains, and affording conclusive evidence that their bearing and upheaval are due to the protrusion of the igneous rocks.[3] This is a point of great geological interest, inasmuch as it enables us to fix the relative age of the trap range and of the bedded trap and conglomerate.

"On the east side of section 14, township 59, range 29, the sandstone is again seen, forming the southern shore of Bête du Gris Bay. Although removed but a few miles from the trap, it is nearly horizontal. The rock is very fissile, some of the layers yellow or buff, while others are brick-red. It contains numerous concretions of dove-colored clay and red ocher, hydrous peroxide of iron."

J. W. Foster and J. D. Whitney, 1848–'49. (Geology and Topography of a Portion of the Lake Superior Land District. Part I. Copper Lands, Washington, 1850. House Documents, No. 69, Thirty-first Congress, first session, 1850, p. 66.) "The conglomerate, north of the axis of elevation, rarely attains a greater inclination than 45°, but on the southern slope, the sandstone is observed dipping at an angle of 78°. This is beautifully exhibited by the lake shore, on section 36,[4] township 58, range 29. The sandstone is seen in the bottom of the bay, composed of alternating bands of white and red, sweeping round in curves, conformable to the course of the trappean rocks. As we recede a few miles to the south, the strata are observed to be

[1] This we take to refer to sandstone patch C of the map of Plate II. Section 27 should evidently read 29, since there is a long stretch of sandstone on the coast of 28 and 29 (the one described by Rominger, *infra*), and no such patch on the shore of section 27, as stated by Rominger and shown also by the survey-notes to the plat of T. 58, R. 28 W. This error is repeated in several other places in reports by Jackson and Foster and Whitney.

[2] There being no section 36 in this township, there is evidently a misprint here. If "36" should read "26," then this statement refers to the sandstone A of Plate II. But there are no such strike and dip to be observed at A, whilst at the embayment B there is something like it for a short distance. The "36" should then read "25." No "abutment" against brick-red conglomerate was observed here, however, though there is some red conglomerate interleaved with the sandstone, but this conglomerate is in no way like that of "the northern slope," nor is there any "chlorite rock." What with the original vagueness of these descriptions and the numerous misprints characteristic of the Government documents of that time, it is difficult to tell just what is meant in these and other quotations here given from Jackson and from Foster and Whitney. It should be said, however, that it is possible that some of the unaccountable statements by Jackson and others may refer to an exposure of sandstone in addition to those noted on Plate II and not known to us.

[3] And yet these sandstones are crowded with fragments derived from these same igneous rocks.

[4] Again a misprint, since there is no such section in this township.

nearly horizontal. In the two adjoining townships west, this range preserves its distinctive character; but beyond, it sinks down into sloping hills two or three hundred feet in height."

(Ibid., p. 112.) "On the south side of Keweenaw Point, (section 27,[1] township 58, range 28,) above Bête Gris bay, the sandstone is seen bearing north 22½° east, and dipping southeast, or away from the trap, at an angle of 78°, and can be traced along the lake shore for three-fourths of a mile. It is nearly white in color, composed almost entirely of silicious particles, and would form an excellent firestone. On section 36, township 58, range 29, it is again exposed, flanking a thin band of conglomerate. It here consists of alternating bands of a white and red color, having a high inclination. In the bottom of the bay, when the lake is tranquil, these bands can be seen describing immense curves, conforming in direction to the course of the Bohemian range. This is a point of much interest, as it enables us to solve the problem of the relative ages of the unbedded and sheet trap and of the associated sandstone and conglomerate. Their order of succession is here distinctly traced.

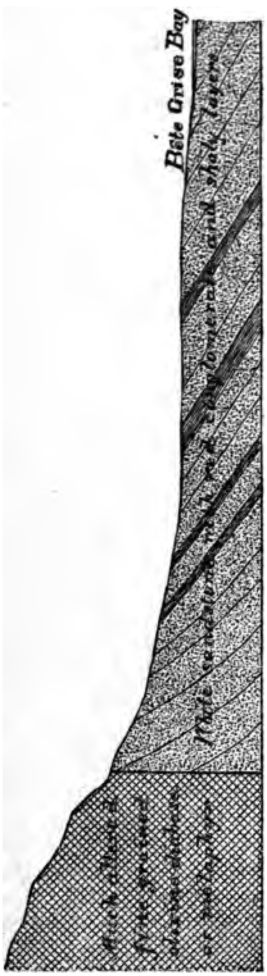


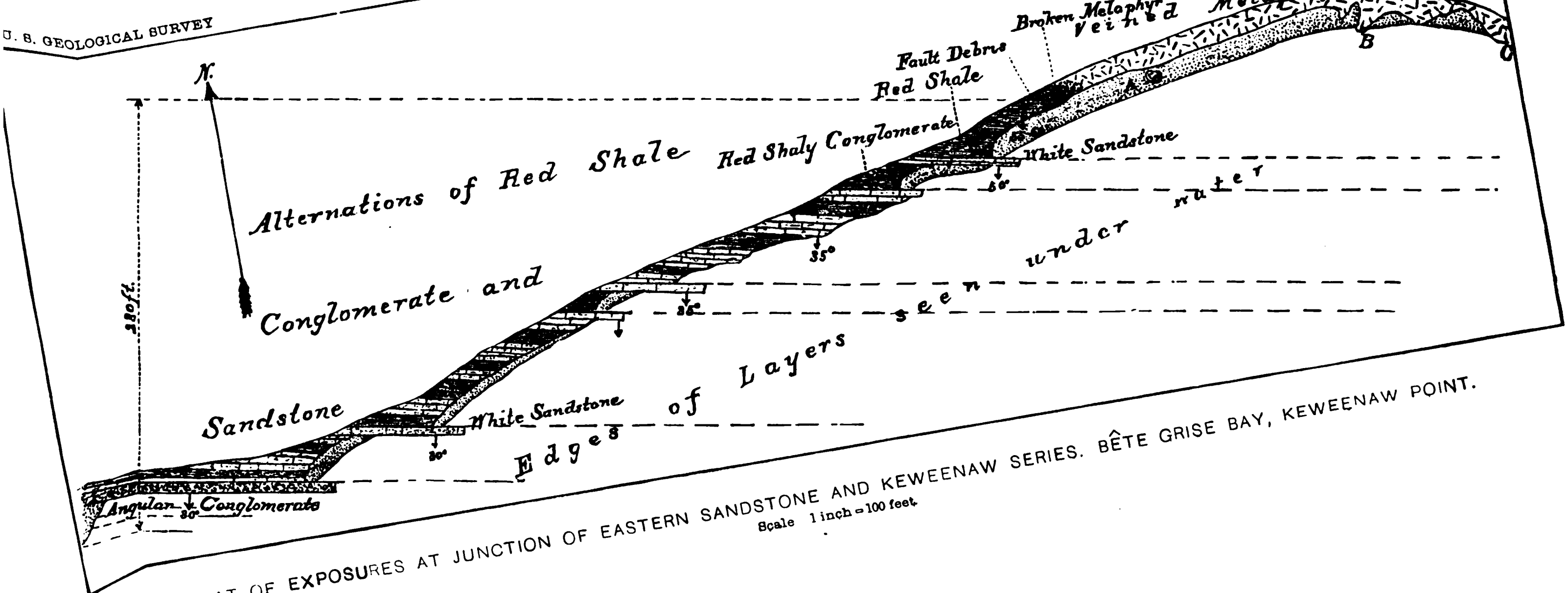
FIG. 1.—Showing relation of the Eastern Sandstone and Keweenawan melaphyr, Bête Grise Bay. Length of section, about 150 feet.

"On the east side of section 14, township 57, range 29, the sandstone is observed in low ledges, forming the southern coast of Bête Gris bay. Although but a few miles removed from the igneous rocks, it reposes in a nearly horizontal position. The rock is very fissile, of a deep-red color, and contains patches of dove-colored clay and ocher, or hydrous peroxide of iron. There are also numerous concretions, resembling, at first sight, the vertebræ or joints of crinoids, the mould being filled with pure white silex, while in the center it is not unusual to see a dark speck corresponding with the alimentary cavity or internal canal."[2]

R. D. Irving, 1880. (Copper-Bearing Rocks of Lake Superior. Monographs United States Geological Survey, Vol. V, Washington, 1883, p. 353.) "The north shore of Bête Grise Bay, as shown on a previous page, is made of low cliffs of Keweenawan diabase and melaphyr, with some quartziferous porphyry, all dipping northward at a high angle; while the west shore of the bay lies in the lowland underlain by the Eastern Sandstone. In the angle of the bay the two formations come together, and their contact may be followed for a long distance. The sandstone, of which a considerable thickness may be seen in continuous exposure, dips southward at angles varying from 55° at the contact to 30° and less at the point farthest removed from the contact. It is made up of alternating whitish, quartzose, fine-grained layers, and thinner ones of red shale; the latter running from a few inches to several feet in thickness. Some of the red layers

[1] Apparently a misprint or mistake again for 29. These statements are plainly repeated from one report to another, the errors continuing throughout. It is singular that when there are such variations in dip and strike at each of the three sandstone localities on the north shore of Bête Grise Bay, single ones, which hold sometimes for a few feet only, should be given in these general statements.

[2] Evidently repeated from Jackson's report, as quoted above.



PLAT OF EXPOSURES AT JUNCTION OF EASTERN SANDSTONE AND KEWEENAW SERIES. BÊTE GRISE BAY, KEWEENAW POINT.
Scale 1 inch = 100 feet.

are strongly conglomeratic, the pebbles being generally of small size and often angular, and composed in the main of red felsite, but also in some measure of the ordinary Keweenawan diabase and melaphyr. The accompanying section [reproduced at Fig. 1], representing a length of about 150 feet, is designed to illustrate the nature of this contact. The junction line between the sandstone and the older rocks is quite irregular, and as the shore of the bay is followed eastward, patches of the sandstone are seen remaining in embayments of the older rocks on the cliff side. Underneath the clear waters of the lake the beveled edges of the alternating bands of red and white sandstone may be traced for hundreds of feet in great sweeping curves. On the south point of Bête Grise Bay, below the ship-canal, the sandstone lies horizontally."

(Ibid., p. 184.) "On the north shore of Bête Grise Bay again, in sections 25 and 26, where the contact with the Eastern Sandstone may be seen, the rocks are prevailingly luster-mottled melaphyrs, though much crumbled, altered and seamed with laumontite and calcite. All of these melaphyrs are exceedingly rich in olivine, which, in the thin section, is chiefly represented by a brown or red alteration-product."

In the same work, p. 74, the above-mentioned luster-mottled melaphyr is described as follows, the specimen from which the thin section was taken having been obtained from near the contact with the sandstone, on the southwest quarter of section 27, township 58, range 28 west:

"Microscopic characters: fine-grained, greenish-black, greasy, 'luster-mottled.' Constituents, as determined by microscope, in order of age: *olivine*, very abundant and wholly altered to a green substance, with brown and red stripes, and crowded with the magnetite into the interspaces of the augites; *anorthite*, fresh, tabular, small; *magnetite; augite*, in the characteristic areas."

C. Rominger, 1884. (Manuscript notes.) "The best of all exposures showing the unconformable abutment of Silurian sandstones against steeply erected beds of the Copper-Bearing group are seen along the shore of Bête Grise Bay.

"Near the quarter-post of the south line of section 26, township 58, range 29, a succession of light-colored sandstone beds, interstratified with brown-colored, brecciated layers filled with small, angular, but somewhat water-worn fragments of porphyry and of diabase, projects above the water-line, dipping southward away from the land, under an angle of about 35°.[1] Out in the shoal water a continued series of such rock-beds is observable, partly of layers which are ripple-marked. Proceeding eastward along the shore we find these beds in contact with luster-mottled diabase, which dips under a high angle northeastward. The diabase on the line of contact is much shattered, and the net-work of fissures in the rock is replenished with a mixture of calcspar and laumonite. The contiguity of the sandstone with the trappean rock, which locally is also an amygdaloid, instead of the luster-mottled kind, can be seen in the lake-bottom for a much greater distance than on the shore.

"Further east another large patch of sandstone occurs on the shore near the center of section 29, township 58, range 28.[2] In the outer portion of this patch the strata dip under an angle of about 20° south, but, following the exposures along the shore eastward, this inclination decreases, and finally, near the spot where the sandstones come in contiguity with the diabase, they are horizontal. The diabase in this locality is likewise the luster-mottled kind, shattered and recemented as in the first locality; the layers show, however, a distinct bedding, and the direction of the dip to the northeast under a high angle is plainly recognizable. The contact of the sandstones with the trap-rock is also from here, for quite a way, traceable in the shoal water. Further east all the shore is formed of diabasic, amygdaloidal and porphyritic rock."

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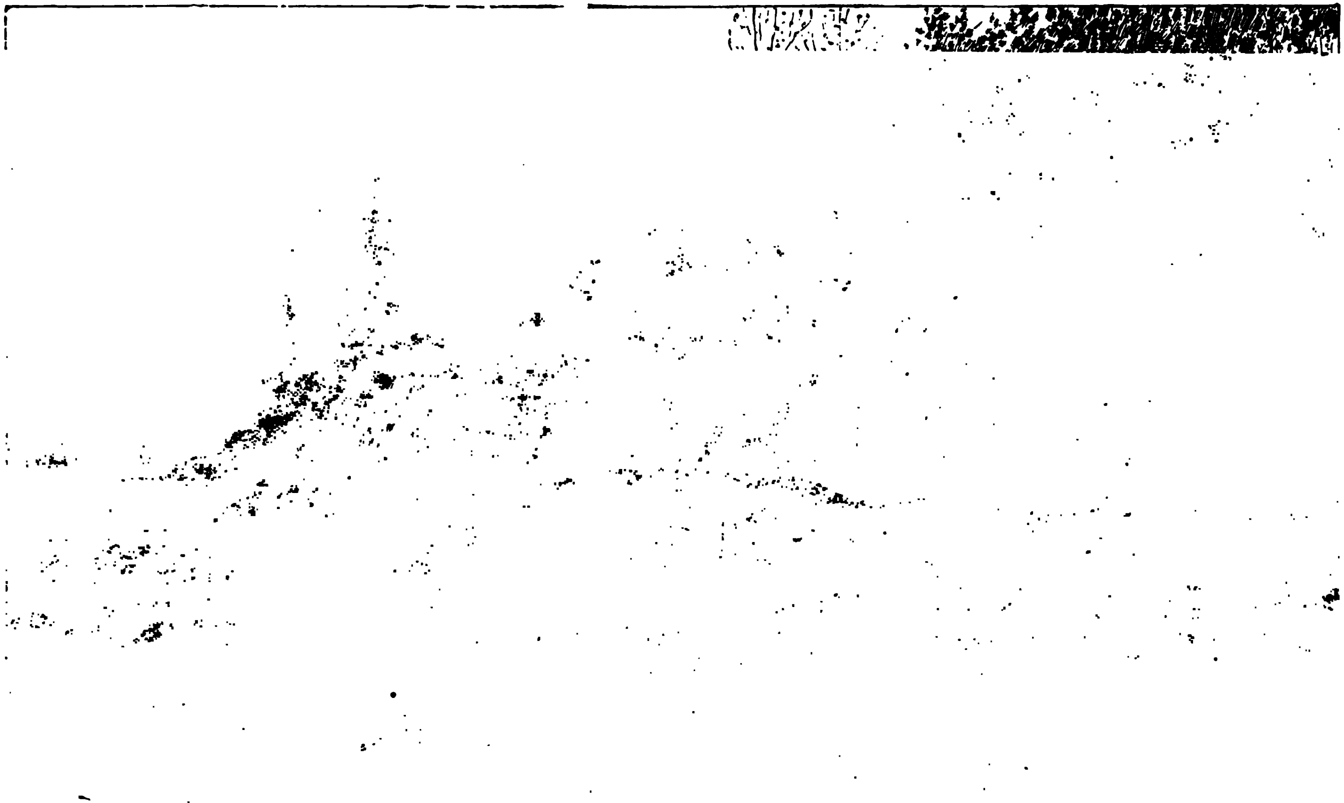
[1] This is the sandstone A of Plate II.
[2] This is the sandstone C of Plate II.

The above quotations apply to three distinct exposures of sandstone on the north shore of Bête Grise Bay. Of these three we examined, in October, 1884, the westernmost two, whose positions are shown on the accompanying map of the north shore of Bête Grise Bay, Plate II. Upon the same map we have inserted the easternmost of the three masses, on the authority of Dr. C. Rominger. These three sandstone patches, though separated from one another by long intervals which are occupied by Keweenawan melaphyrs, diabases, etc., as one sees them on the cliff line, are actually in direct continuity with one another underneath the waters of Bête Grise Bay. Here, in calm weather, the water being shallow and exceedingly clear, the connecting masses of sandstone can be followed, and even, as Dr. Rominger has stated in the quotation above given, the junction line between the sandstone and the traps can be traced.

As one follows northward the long sand beach which forms the western margin of the bay, the first rock met with is a reddish, clayey and often shaly sandstone, thickly crowded with dark-colored fragments of the various eruptives of the Keweenaw Series, for the most part quite angular. The angularity of these fragments is exceedingly striking, and is quite convincing as to their nearness to the parent rocks. They run from the size of a pea up to two or three inches, and occasionally even more, in diameter. In the above quoted description of this place, previously published by one of us, these pebbles are spoken of as prevailingly of some of the acid members of the Keweenaw Series, although it is noted that fragments of the basic eruptives are also abundant. On the re-examination, however, the greatly prevailing dark color of the fragments struck us as very noticeable, and on breaking open a number of them we became convinced that pieces of the basic rocks are quite largely predominant, though numbers of them are plainly derived from the usual felsitic and granitic porphyries. Among the basic fragments many derived from the matrices of the ordinary diabases, amygdaloids and pseud-amygdaloids were recognized, as also numerous others derived from the luster-mottled melaphyrs. Although they are often considerably altered, the recognition of the fragments as derived from those eruptives is perfectly simple and easy to any one familiar with the Keweenawan eruptives. Moreover, in a number of instances our recognitions have been confirmed by the study of these fragments in the thin section. This conglomerate layer is in all some four feet thick, but in the middle of this thickness is included an eight-inch seam of red clayey shale, the pebbles disappearing. Above the conglomerate are seen three inches of white quartzose sandstone, one inch of red shale, three feet of fine angular reddish conglomerate, and then other reddish layers which were not closely examined, being covered by the waters of the lake.

Beneath the conglomerate bed first described are three feet in thick-



ness of a reddish sandy shale thickly studded with mica scales; and beneath this again a white quartzose sandstone. The thin section of this sandstone showed that while it is composed in great predominance of quartz fragments, many of which, here and there, show secondary enlargements,[1] there is yet contained a quite noticeable proportion of fragments derived directly from the basic members of the Keweenaw Series. Occasionally the fragments are large enough to be seen in the hand specimen with the naked eye. When distinctly recognizable microscopically they are seen to have been chiefly derived from the matrices of some of the amygdaloids, being composed of minute tabular plagioclases imbedded in a non-polarizing red-stained matrix. These fragments are noticeably angular, and in this respect present a striking contrast with the quartz fragments of which the rock is mainly composed.

Beneath this sandstone layer succeeds now a series of alternations entirely similar to those already described; the white sandstones, on account of their greater hardness, frequently projecting towards the lake in such a way as to overhang the little shingle beaches that have been formed behind them. The red shale layers and shaly conglomerates, on the other hand, being soft, have usually washed to a more uniform surface, and, in several instances, they have been found forming the cliffs at the bottoms of little coves, whose sides are made of the layers of harder white quartzose sandstone. These white sandstones contrast very strongly in color with the red shales and conglomerates with which they are interstratified, and, underneath the waters of the lake, the edges of the alternating red and white layers may be traced for long distances in great curving bands. As this succession of layers, which strike S. 80° E. (true), is crossed to the northward, they are found to take steeper angles of dip, the northernmost layers seen reaching 55° and even 60° in southward inclination. Indeed, the increase in dip is often noticeable in individual layers; for instance, in the first white sandstone layer to the southward of the more northerly rocks next to be described. The position of this particular layer is indicated on Plate IV, and is also shown at the left of Plate III, which is taken from a photograph, the direction of outlook being south of west from the point A of the first-named figure.

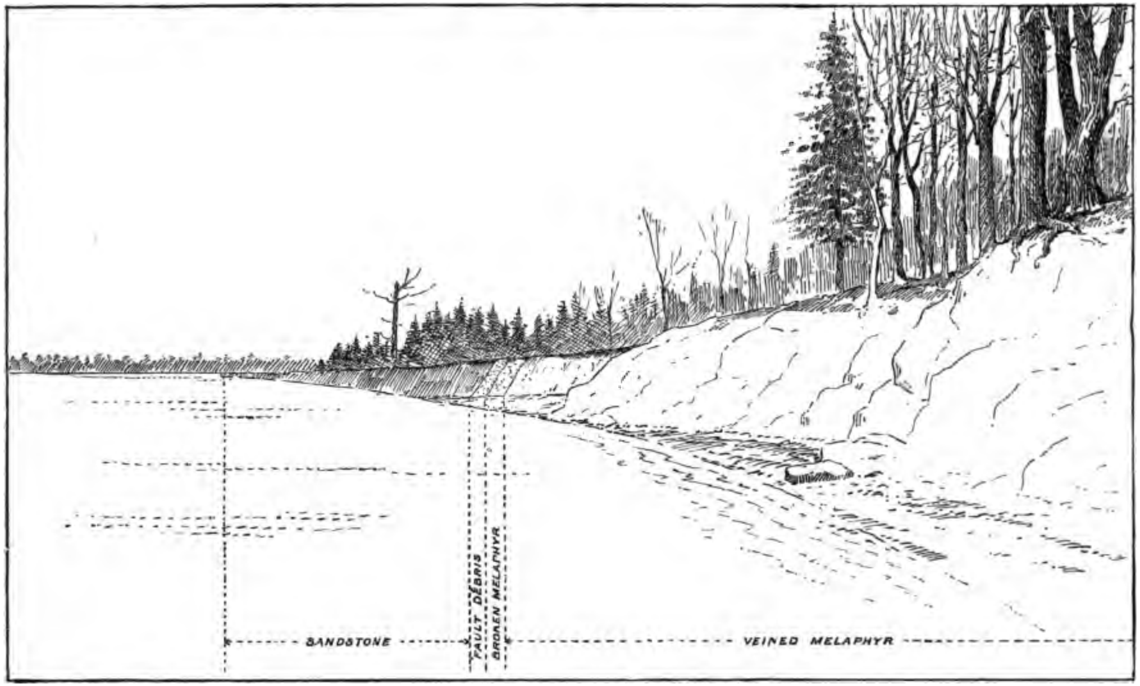
Immediately to the north of this sandstone layer comes in a belt of very soft red shale and shaly breccia. The position of these red layers is indicated on Plate IV. In the views of Plates III and V they also show in the left center of the picture, extending from the shovel shown lying against the bank as far as the projecting layer of white sandstone above mentioned. Measured along the bank, which here trends north of east, these layers have a width of some twelve paces. They are alternatingly quite soft red shales, containing numerous minute mica scales,

[1] See Bulletin No. 8, United States Geological Survey.

and layers of sharply angular fragments of the various Keweenawan eruptives thickly set in a red shaly matrix. Among these fragments, which in the main are rather smaller than those seen in some of the higher conglomerate or breccia layers, many are recognizable as identical with the altered, luster-mottled melaphyr lying immediately to the north, or, as one follows the course of the bank, to the northeast.

These soft, red layers, and the broken and altered rocks immediately to the north of them, had so crumbled and weathered down that, in order to make out the exact succession here, we were obliged to strip the bank somewhat thoroughly for a distance of some 30 feet. On doing this we found immediately beneath the red layers just described, which essentially form the base of the Eastern Sandstone at this place, about three inches of a red clay resembling what is sometimes found in joints or fault fissures. In this clay, however, are some traces of a lamination according with that of the shales above, so that we did not feel certain as to whether it should be looked upon as a fissure clay or as forming the base of the red layers immediately to the west and south. It seemed to us, indeed, that this clay might belong in some measure to each of these categories; *i. e.*, might be the base of the red shale rubbed into a joint clay by faulting motion. The position of this clay seam is indicated by the shovel in the view of Plates III and V.

Measuring along the bank eastward from the red-clay seam just described, we find a 9-foot face of a breccia, formed of fragments, mainly from one to four inches in maximum dimensions, but occasionally reaching a foot. The greater part of these fragments are similar to the melaphyr seen in the bank immediately to the eastward; but some are compact, dark-colored diabase, similar to a rock that lies along the shore some thirty rods or more to the eastward. Others again are compact, fine-grained and dark brownish, and may in some measure belong to the acid or intermediate rocks of the Keweenaw Series, but on the ground we took them to be mainly of some of the basic kinds. They are all angular or subangular, but for the most part show some blunting of the angles. Between them often lies a reddish clay, like joint clay, that does not appear to form a true matrix, as in the case of the conglomerates farther to the south and west. As the fragments are taken out this clay commonly coats them, and in many cases shows strongly marked, shining, "slickensided" surfaces. This zone of breccia, then, we do not take to be a part of the sandstone series proper, but rather to be a junction débris which has resulted from a faulting motion that has taken place between the sandstone and the trappean series. It seems quite possible that decomposition, which is so common a phenomenon at the contacts of diverse formations and which is so apparent in the adjoining melaphyrs, had prepared the way for the easy production of this débris. In the view shown in Plates III and V



GENERAL OUTLINE VIEW OF THE JUNCTION OF THE EASTERN SANDSTONE AND KEWEENAWAN MELAPHYR, BÊTE GRISE BAY KEWEENAW POINT.

this zone stretches to the right from the shovel to the first pole laid against the bank. Its position is shown on Plates IV and VI.

As indicated on Plate IV, the entire width of the sandstone series here exposed, measured upward from the upper limit of the breccia zone just described and at right angles to the strike, is 230 feet. With an average dip angle of 35° this width corresponds to a thickness of 133 feet.

Next east of the zone of fault débris the bank shows a face of eight feet in width of much-broken, altered and decomposed melaphyr, embracing a considerable proportion of secondary matter, especially chlorite and calcite. The position of this zone is indicated in the several figures already referred to. In the view of Plate III it extends between the two poles seen lying against the bank. It is not separated, however, from the brecciated zone immediately west of it by any definite line; the two grade into one another insensibly. Neither is there any distinct line of demarkation between this zone and the melaphyr, which extends some distance farther eastward.

Following the bank eastward, this melaphyr is found becoming more and more compact, though much veined with laumontite and calcite. At the point B of Plate IV it comes out to the water's edge and forms the bounding cliff of the bay. Here the rock is much fresher, and is seen to be one of the typical luster-mottled melaphyrs of Pumpelly.[1] The luster-mottling is rather small, the rock belonging to one of the finer-grained phases of its class, but is rendered quite apparent on weathered surfaces by the reddish decomposition of the olivine and probably also of interstitial glassy substance. In the thin section the olivine is seen to be peculiarly abundant and in unusually large grains for the size of the luster-mottling. It is wholly altered to a greenish material, which is also often combined with much oxide of iron. The plagioclase, which from the angular measurements appears to be near anorthite, and the augite are both often quite fresh. The usual magnetite is present. The dip of this rock is not satisfactorily seen at this place, inasmuch as for a considerable distance we are dealing with only one great flow. Nevertheless, from the general occurrences elsewhere met with along the Bohemian or southern trap range of Keweenaw Point; from the northern dips which characterize the section immediately to the northward of this as far as Mount Houghton; from the similar northern dips met with within half a mile to the eastward, along the Bête Grise cliffs, where one of us saw in 1880 at least one bed of conglomerate interstratified in the traps; and from the similar northern dips described by Dr. Rominger as obtaining all along the coast to the extremity of Keweenaw Point and along the lower reaches of the Mon-

[1] Metasomatic Development of the Copper-Bearing Rocks of Lake Superior, Proceedings American Academy of Sciences, Vol. XIII, pp. 269–270; Geology of Wisconsin, Vol. III, p. 33; Copper-Bearing Rocks of Lake Superior, Monographs United States Geological Survey, Vol. V, pp. 68–77 and Plate IX.

treal River—it is believed that the inclination here is at a very high angle to the northward, with the strike to the north of east.[1]

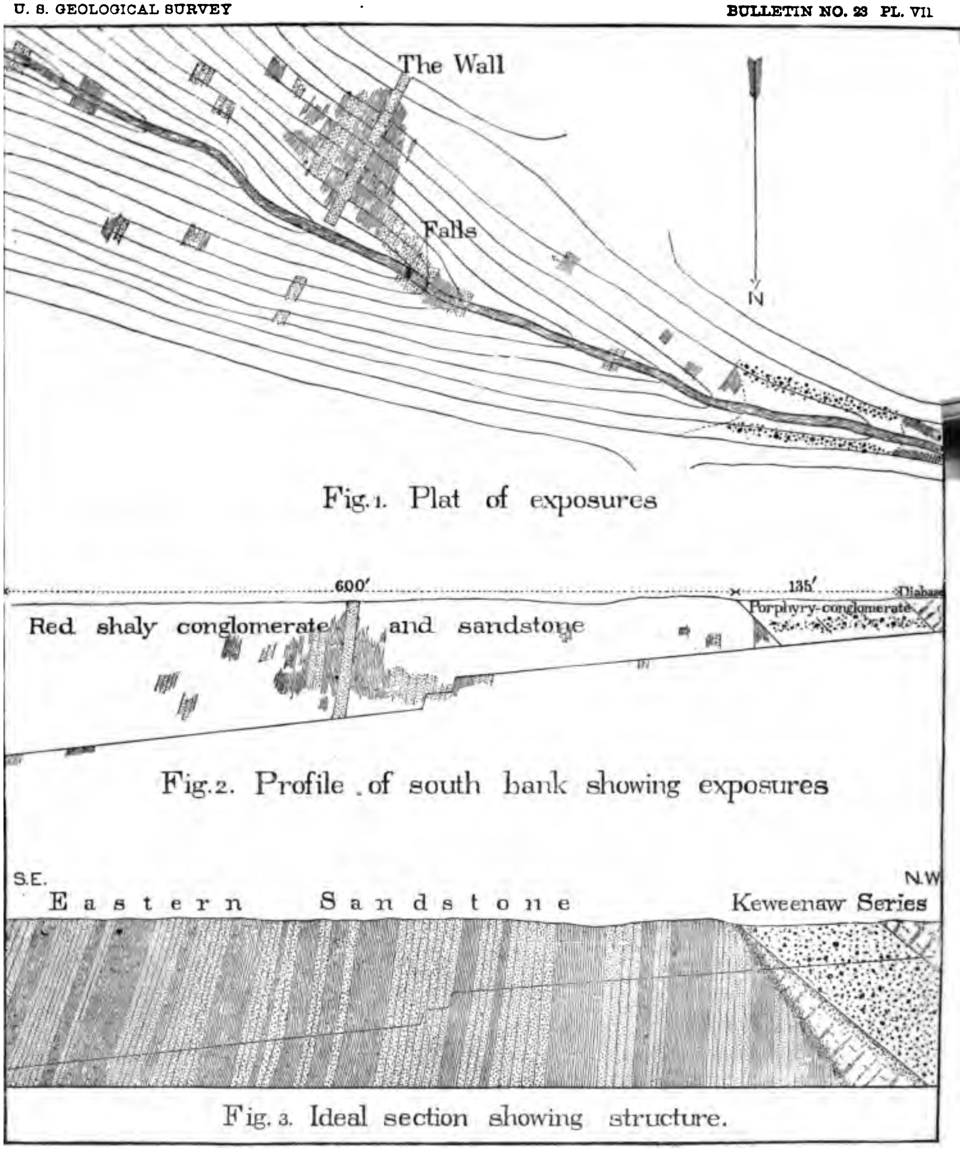
The sketch of Plate VI is a general outline view of the various exposures above described looking south of west from the point C of Plate IV. In the distance is seen the low land immediately behind the long sand beach which forms the western shore of Bête Grise Bay (see Plate II). In the middle distance are shown the alternating sandstones and conglomerates of the Eastern Sandstone dipping southward. Following these towards the foreground, we come upon their junction with the traps at the central point of the sketch. The irregular rocks in the foreground are composed of black melaphyr, and are the same as shown at the extreme right of Plate IV. A photograph was taken showing this same view, but unfortunately when the plate was developed it did not prove to be sufficiently successful for reproduction. The outlines of the view were, however, sufficiently distinct for us to trace from, and in that way we have constructed this sketch.

The second of the three sandstone localities on the north shore of Bête Grise Bay is the one marked B on Plate II. Between it and the

FIG. 2.—Embayment of Eastern Sandstone at B of Plate II; north shore Bête Grise Bay.

sandstone exposures at the northwest angle of the bay, already described, the cliffs are entirely composed of Keweenawan melaphyrs and diabases, which strike in this distance apparently more to the northward than the coast line, and rise very abruptly from the shore-cliff into heights of more than 500 feet. At the westernmost point of this exposure of sandstone it is found striking N. 39° E., or sharply in shore, and dipping 46° to the southeast, while within a few steps to the westward the Keweenawan diabase is seen. This, then, is the same junction as above described, where the strike of the sandstone was, however, S. 80° E. Between the two places much of the northern edge of the sandstone may be seen beneath the waters of the lake. This northern edge thus forms a great curve, which here reaches the shore again in its course. Continuing our examinations of this sandstone to the eastward, we find the strike gradually changing, until, at 25 paces from the beginning, it is only 9° east of north, with an eastward dip

[1] Copper-Bearing Rocks of Lake Superior, Monographs United States Geological Survey, Vol. V, pp. 179–185; also Plates XVII and XVIII.



JUNCTION OF THE EASTERN SANDSTONE AND THE KEWEENAW SERIES, WALL RAVINE.

Scale: 1 inch = 150 feet.

of 55°. Nine steps further there is a sudden overturn, and a little synclinal appears in the cliff face, the dip in the bottom of the synclinal being 24° to the north, and strike N. 79° E. Ten steps further this dip is changed again for one of 65° to 75° to the southeast, and the sandstone layers can be followed in nearly vertical position along the cliff line, which here forms a re-entering curve, corresponding to a similar curvature in the strike of the sandstone layers. As we follow this curving cliff eastward, the dip of course changes gradually to a southerly and again to a southwesterly one, at the same time first increasing to verticality and a few degrees beyond, and then returning to a somewhat flatter dip. Underneath the water in front of the cliff a long succession of similarly curving bands of sandstone may be seen. Finally, at about 20 rods from the beginning, the sandstone leaves the coast again, striking in a southeasterly direction, and the cliff is composed once more of the ordinary Keweenawan eruptives, which rise immediately behind in bold bluffs several hundred feet in height. From the face of the Keweenawan traps the sandstone has in part fallen away, but in part it has adhered to them and the exact contact may be seen. It is noteworthy that the trap at the contact is not now a luster-mottled melaphyr, but is, on the contrary, one of the ordinary diabases of the Keweenaw Series, much altered and more or less fine-grained. The sandstone here is of the same nature as at the first described place, being prevailingly quartzose, interstratified with reddish shaly portions and carrying in some parts many fragments of the underlying rocks. Nevertheless it is evident that the contact here is not at exactly the same horizon of the sandstone series as in the other instance.

To the eastward from this place we know at present of no sandstone on the land except that at the point C of Plate II. Not having examined this point ourselves, we do not attempt to add anything to the statements of Dr. C. Rominger, above quoted. Between these two points, however, the curving edges of the south-dipping sandstone strata may be traced for considerable distances. Possibly they could be followed for the whole distance in calm weather. From the appearances one of us saw along the shore of section 30 from a boat, being unable to land, he suspects that there may be here at least one more embayment of the sandstone like that at B.

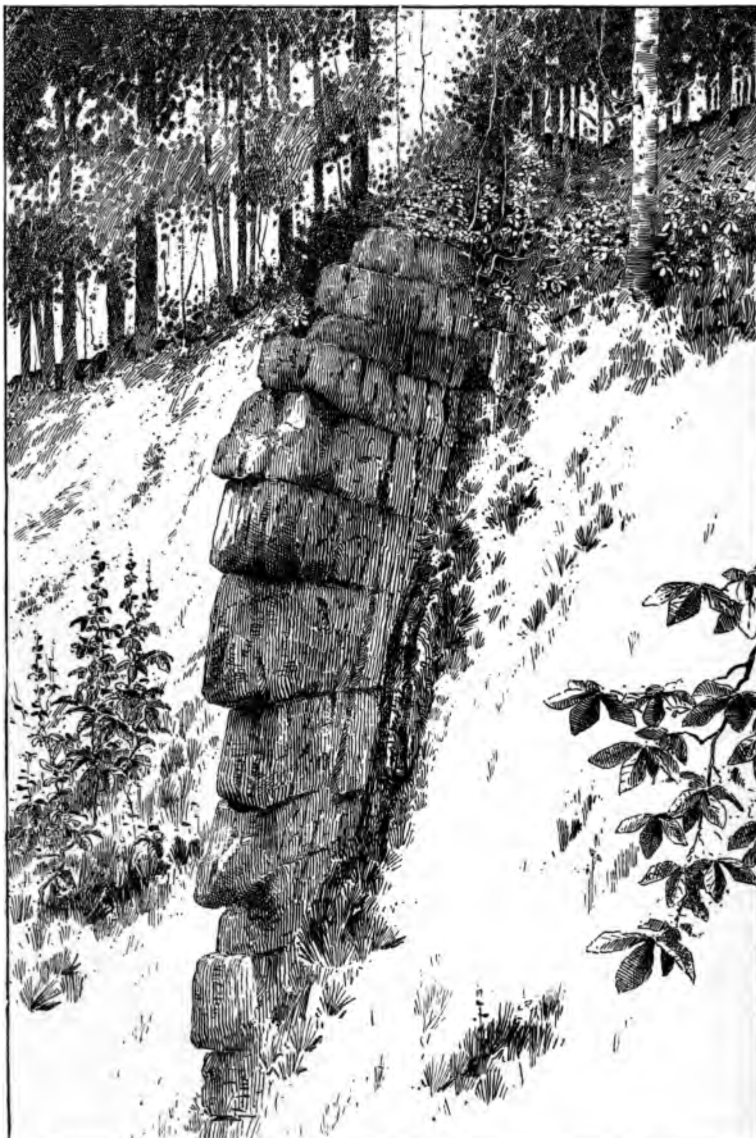
WALL RAVINE.

The ravine to which we have given this name, on account of the somewhat striking natural wall of sandstone extending into it from the south side, lies in the north half of Sec. 20, T. 56, R. 33 W. Our attention was first drawn to this very interesting and important place by Mr. West, chief engineer of the Calumet and Hecla mine. So far as we have been able to learn, no geologist had previously made any ex-

amination of this place; certainly we have met with no reference to it in the various publications with regard to Keweenaw Point geology. The portion of the ravine which was examined by us in detail is indicated in plan on Fig. 1 of Plate VII. At the eastern end of the area there mapped, in the bed and on the sides of the stream, we noted red shale and white quartzose sandstone, dipping down stream, or southeasterly, at an angle of 60° to 65°, the individual layers being seen to curve from the flatter angle below to the steeper one above.

Following now the bed of the stream upwards, we found, at 30 steps from the first exposure, another one of red sandy shale, holding pebbles of various Keweenawan eruptives, basic and acid, exposed in a slide at the foot of the wall of the ravine and also in the bed of the stream. Here the same curvature as before was seen, but the dip is now increased to 75° southeast. Farther up-stream for 75 paces both walls of the ravine show partially covered exposures of red shale and shaly conglomerate, with interstratified seams of harder, white, more purely quartzose sandstone, upon which we did not make any measurements, but all of which, so far as we observed, present the same high dip down-stream.

Much more satisfactory exposures, however, begin at the end of these 75 steps, and continue up-stream for some distance. These exposures are in the south bank of the ravine. First, on a steep bank, where a recent slide has uncovered the rocks, is seen a series of alternating layers of red shale, shaly conglomerate and reddish, purely quartzose sandstone, all inclining to the southeast some 75° to 80°, and resembling closely the alternations already described as met with in the northwest angle of Bête Grise Bay. One point of difference from the Bête Grise succession is to be noted, however. This is the larger size and more perfect roundness of the pebbles of the conglomerate. While these are, to some extent, subangular, they never show the sharp angularity of the Bête Grise pebbles, but, on the other hand, are often unusually well rounded, and range from the size of a pea to bowlders 18 inches in diameter. These pebbles, while all plainly derived from the eruptives of the Keweenaw Series, are less prevailingly from the basic rocks than in the Bête Grise conglomerate, a considerable portion of them having come from the Keweenawan felsites and granitic porphyries. The characteristic diabases and amygdaloids are, however, abundantly represented. While on the ground we saw several good-sized subangular fragments, which we took to be from some of the finer grained Keweenawan porphyry-conglomerates, an observation which would be confirmatory of the very important statement made by Agassiz and Pumpelly as to the occurrence of conglomerate fragments in the Eastern Sandstone at the Douglass Houghton and Saint Louis ravines. The one among these fragments which was brought home proved, however, on closer examination in the hand specimen and thin section, not to be from a conglomerate, but from a granitic porphyry somewhat crumbled from de-



"THE WALL," WALL RAVINE, KEWEENAW POINT. WEST SIDE.
[From a photograph.]

composition. We are unable, therefore, to assert with the positiveness

[illegible]

cularly the case with the smaller fragments. The rock is considerably

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composition. We are unable, therefore, to assert with the positiveness that we could wish that such fragments actually occur, though on the ground we had no doubt of their occurrence.

The land-slide showing these conglomerates, shales, etc., is terminated on the up stream side by a massive layer, some three feet thick, of nearly white, purely quartzose sandstone, which projects from the side of the ravine in a wall some 90 feet in greatest height and 40 feet in greatest projection from the slope. This wall is shown in view on Plates VIII and IX, both of which are from photographs taken by us from the opposite or north side of the ravine, the first named showing the southeast side of the wall, the other its northwest side. The strongly marked horizontal joints, which are shown in the figures and which so greatly increase the resemblance of the rock to artificial masonry, are not bedding planes, but cross joints, the direction of the bedding being that of the wall as a whole. At the foot of the wall its inclination is 78° to the southeastward; half-way up 80°, and, at the top, about 85°; the course of the wall being 26° east of north. The curvature from flatter to steeper dips already noted as seen in certain layers farther down stream is thus further illustrated here. On the opposite side of the ravine the same layer of white sandstone projects in a less strongly marked manner. There is not the least possibility of mistake or erroneous interpretation as to the vertical position of the layer forming the wall and of the entire succession of sandstones and conglomerates. The bands of shale and conglomerate occur on both sides of the wall in concordant attitude with it.

Up-stream from the wall similar vertically placed sandstones, red shales and red shaly conglomerates continue to appear in the bed of the stream, where they produce two small falls, and in the sides of the ravine with some interruption, until, finally, the junction of the sandstone with the undoubted Keweenawan rocks is met with. The latter rocks are represented here, as indicated on the topographical sketch and section of Plate VII, by a characteristic porphyry-conglomerate about 135 feet in width, immediately overlying which are diabase and diabase amygdaloid. The occurrences at the exact junction, upon which we made a considerable excavation with the aid of a force of miners, are shown in the accompanying sketch, page 26.

The conglomerate, which just above on the banks of the stream shows in natural exposures of considerable size, appears in the excavation in a somewhat fissured mass. This mass, however, is evidently essentially *in situ*, since it retains the characteristic northwestern dip of the series in the vicinity. The pebbles of this conglomerate are, for the most part, rather fine, but occasionally reach a considerable size, and are commonly of some of the acid eruptives of the Keweenaw Series, particularly of the felsitic kinds. There is a plentiful mixture, however, of fragments derived from the basic Keweenawan eruptives, this being particularly the case with the smaller fragments. The rock is considerably

indurated, and in the thin section the induration is seen to be due to a plentiful saturation by calcite.

Obliquely beneath the under face of the conglomerate, which did not present the appearance of a definite bedding plane, lie about 15 inches of broken, rounded and crushed rock, imbedded in a dark, reddish-brown clay, which is manifestly of an entirely different nature from the indurated matrix of the conglomerate immediately above it. Next below this clay follows a thick mass of dark shaly material, embracing trap débris and fragments of conglomerate and sand from the Eastern Sandstone. This mass is evidently of the same nature as the material met with at the same junction at Bête Grise Bay, as already described, and on the Douglass Houghton and Hungarian rivers, as subsequently

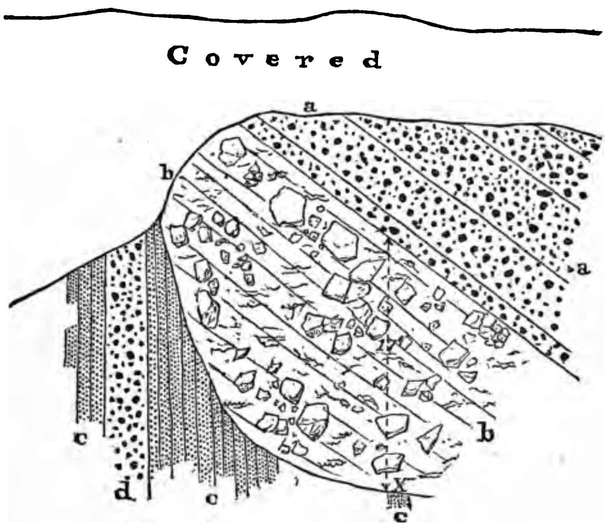


FIG. 3.—Junction of the Eastern Sandstone and Keweenawan porphyry-conglomerate, Wall Ravine, Keweenaw Point. *a a*, Keweenawan porphyry-conglomerate; *b b*, junction débris; *c c c*, vertically placed Eastern Sandstone; *d*, conglomerate layer included in *c*.

described. It is to be noted that this junction formation, which is so manifestly the same at all of these places, is in contact at no two of them with the same horizon of either the Keweenaw Series or the Eastern Sandstone. On the contrary, it is in contact with horizons which must belong many feet apart in the different cases. It is thus manifestly not a stratum of either one of the two formations concerned, but belongs in the space between the two. Measured in the excavation, along a line normal to the Keweenawan conglomerate, beginning at a point about 12 feet below the top of the bank of the ravine, the thickness of this joint material was found to be 10 feet and 4 inches. Measured on a line normal to the sandstone next to be mentioned, the thickness is 14 feet.

Next down stream from the joint material just described, comes the Eastern Sandstone, which is here of the normal quartzose type, being

"THE WALL," WALL RAVINE, KEWEENAW POINT. EAST SIDE
[From a photograph.]

white and friable. In the thin section, the rounded particles of this rock

ite and friable. In the thin section, the rounded particles of this rock e seen to be composed almost wholly of quartz, many of the grains owing slight secondary enlargements. Mingled with the greatly preminant quartz grains are a few of orthoclase and plagioclase and of e matrices of Keweenawan diabasic and felsitic eruptives. Between e grains there is a somewhat plentiful filling material of kaolinic subance and fine quartz, with here and there a flake of muscovite. The nction face between this sandstone and the joint material varies beeen S. 35° E. and S. 45° E. in bearing, and stands about vertically seen in the excavation, but the appearance of sandstone at the point (p. 26) of the sketch, immediately at the base of the excavation, seems indicate that the face of the sandstone is not plane, but on the contrary at it descends by offsets. The bedding of the sandstone at the juncon is approximately vertical, coincident with what is seen farther down e stream, as already described. This is rendered plain, not merely joints in the sandstone, but by the presence here of one of the layers coarse pebble conglomerate.

In Figures 1 and 2 of Plate VII we have attempted to show exactly e extent and positions of the exposures actually seen along this ravine far as we examined it. In Figure 3 of the same plate we give the ructure which, as we think, these exposures plainly indicate.

In the distance examined by us below the junction of the sandstone id Keweenaw Series, there is displayed a thickness of sandstone with terstratified shale and conglomerate of little less than 600 feet.

SAINT LOUIS RAVINE.

This ravine begins in Sec. 19, T. 56, R. 32 N., and runs thence rough parts of sections 20 and 29 of the same township. The exposes on it examined by us lie in the vicinity of the old Saint Louis ine. The place is easily reached from Calumet by the old road to orch Lake. The following quotation, from a paper by Mr. Alexander gassiz, comprises the only published reference to this place that we ave met with:

Foster and Whitney, in their report of the Lake Superior mineral district, represent e sandstone on the south side of the trap range of Keweenaw Point, as dipping nth and resting conformably upon the beds of trap of the north side of the antinal axis of Keweenaw Point. This anticlinal axis, formed by the Bohemian untain, as asserted by Foster and Whitney, is not found farther south, as far as ave had occasion to examine. In two of the ravines cut through the sandstone creeks flowing in an easterly direction from the crest of the range towards Torch ver, near the head of Torch Lake, we find good exposures of the sandstone, and in o points, one of which was examined by Foster and Whitney, we find the sandne resting unconformably upon the trap which has still the same northern dip as ther west, of about 42°. The sandstone within a distance of 100 feet from the p, dipping north 42°, lies horizontally, or rather has at the outside an inclination 1½° or 2° south. The peculiar bed of chloritic rock, so characteristic of the juncn of trap and sandstone as described by Foster and Whitney, is well marked, but

we can find no trace whatever of any anticlinal axis at these two ravines, which are about 2 miles apart and present identical features. One of these ravines commences in the property of the St. Louis Mining Company, Section 19, Township 56, Range 32 North, about $1\frac{1}{4}$ miles south of Calumet. An old adit entering from the ravine into an abandoned lode plainly shows that the formation still dips about 42° north. About 600 feet farther east, following the ravine where the dip of the formation does not change, we come upon the bed of chloritic rock forming the junction of sandstone and trap, and about 100 feet farther down the ravine we come upon horizontal beds of sandstone reaching to the very crest of the ravine, here about 100 feet deep, plainly showing that the sandstone rests unconformably upon the trap which has a dip of 42° north. These same horizontal beds can be traced the whole length of the ravine for a distance of over $1\frac{1}{4}$ mile. (On the Position of the Sandstone of the Southern Slope of a portion of Keweenaw Point, Lake Superior. Proceedings of the Boston Society of Natural History, Vol. XI, 1866–1868, pp. 244, 245.)

Fig. 1 of Plate X is a topographical sketch of the portion of this ravine examined by us, based upon pacings and coursings measured with hand compass.

A few steps above the old stamp mill at the Saint Louis mine there is an artificial opening on a bed of porphyry-conglomerate six and a half feet thick, the contacts with the underlying amygdaloid and overlying diabase being both visible. The dip of this conglomerate bed we made by careful measurements to be 47° NW., its bearing N. 36° E. (true). The display here is so entirely satisfactory as to leave no doubt whatever with regard to the general northwesterly dip of the Keweenawan rocks at this place.

Eighty-five steps down stream from this place, on the same bank, at a point between 40 and 50 feet above the bottom of the ravine, the junction with the Eastern Sandstone was found. The sandstone at the junction and its included bed of conglomerate dip here towards or beneath the Keweenawan rocks at an angle of about 70°, striking with the face of the hill, or N. 40° to 42° E. These measurements were made on the junction between the sandstone and an included conglomerate layer, so that no room is left for doubt as to their correctness. The sandstone here is of the usual quartzose type, and both it and the included conglomerate are entirely like those seen at the junction on Wall Creek already described. In the bank above the sandstone the Keweenawan diabase rises in a large exposure some 10 or 15 feet in height. For lack of time we were unable to excavate here sufficiently to uncover the absolute contact of the two formations, but enough was done to carry the diabase to within two feet of the sandstone, and to convince us that the phenomena here are entirely analogous, with one exception, to those met with at the junction on the Wall Creek Ravine.

The exception is the northwesterly dip of the sandstone here displayed at the contact. But this is plainly an overturn dip, and not one indicative of a passage of the entire sandstone series beneath the Keweenawan, for, in the first place, the dip of the sandstone, 70°, does not conform to that of the Keweenawan rocks, 47°; and, in the second place, we find as we pass down-stream from the junction that the dip

low the junction, for had he seen them he could not have failed to notice them in his paper. It is possible that the removal of timber on the summit has somewhat increased the tendency to freshets and has aided excavation and undermining in the ravines and the production of land-slides on the slopes, and that as a result exposures are more abundant than formerly.

DOUGLASS HOUGHTON RAVINE.

The junction of the Eastern Sandstone with the Keweenaw Series occurs in this ravine in Sec. 36, T. 56, R. 33 W., not far from the east line of the section. From here the ravine runs east and southeast through Sec. 31, T. 56, R. 32 W., to the low land about Torch Lake. That portion of the ravine which is of interest in this connection is mapped on Plate XII.

This ravine has attracted the attention of several geologists during the past forty years. The published descriptions of the occurrences here to be met with afford an amusing instance of the very different appearances which the same place may present to different observers. In this case, however, the differences between the several descriptions, while proceeding in part from preconceived notions as to the phenomena which should occur here, have probably not been altogether so derived. The fact is that the occurrences, unless examined in considerable detail, are very confusing. Within a few feet of each other quite contradictory dips and strikes are to be obtained in the sandstone, so that it is not altogether unnatural that discordant views as to the structure here should have been held, the several observers having devoted themselves probably to different points without examining the whole ground. Even the opposite sides of the ravine present sections differing in some important respects from one another. In addition to the difficulties arising from the confused structure of the sandstone are others presented by the decomposed and often shattered condition of the Keweenawan beds and by the steep and slippery sides and wooded character of the ravine.

The following quotations comprise all that we have found with reference to this place :

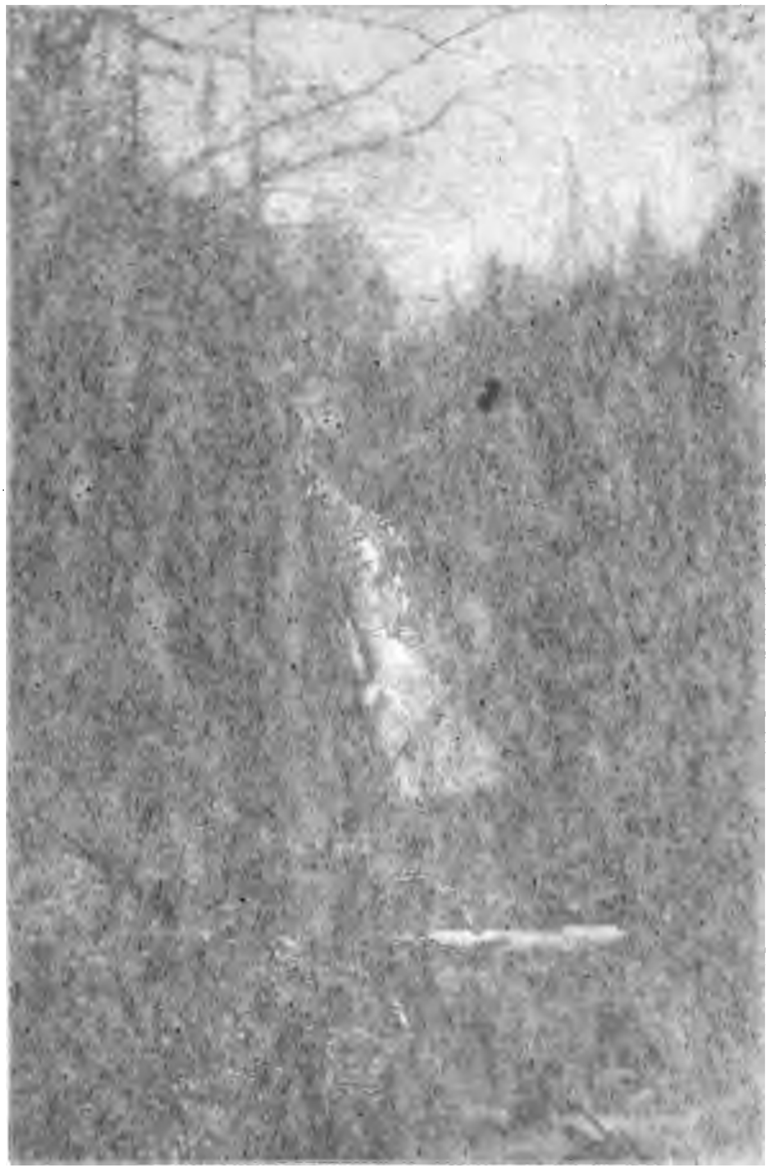
J. W. Foster, 1848. (Report to Dr. C. T. Jackson, dated Boston, May 26, 1849, Senate documents, Thirty-first Congress, first session, 1849, Vol. III, No. 1, p. 782.) "The southern junction is more clearly defined ; but the conglomerate, which is found in such heavy masses on the northern slope, is almost entirely wanting.

"Section 36, township 56, range 33, belonging to the Douglass Houghton Mining Company, affords a good exposure of the rocks. The west fork of Torch river is here precipitated over a cliff of trap 80 feet in height, near the junction, and thence winds along through a deep gorge which it has excavated in the sandstone. The sandstone is of a light yellow color, and contains numerous pebbles, consisting for the most part of white quartz. It dips southerly or away from the trap. On the north side of the stream, it is seen resting on the trap in large blocks, 70 feet above its bed. The sandstone is seen in the banks of this branch of Torch river at short intervals, and contains greenish patches, giving it a somewhat variegated appearance."

FALL OF DOUGLASS HOUGHTON RIVER, KEWEENAW POINT, MICHIGAN.

[From a photograph.]

[illegible] seemed to gain corroboration in the fact that, on the western side of



From a photograph

J. W. Foster and J. D. Whitney. (Report on the Geology and Topography of a portion of the Lake Superior Land District. House documents, Thirty-first Congress, first session, 1850, No. 69, p. 67.) "On one of the affluents of Torch river, (section 36, township 56, range 33,) the junction of the trap is beautifully displayed. The stream is precipitated over a wall of trap 80 feet in height, and thence winds its way through a deep gorge which it has excavated in the sandstone. The conglomerate differs from the lenticular bands described as occurring with the bedded trap, consisting of arenaceous particles loosely aggregated, and containing, near the base, quartzose pebbles. Patches of green and red ochrey clay occur in different parts of the mass, in a concretionary form.

The red and green chlorite rock, fissile, but not stratified, enveloping masses of amygdaloid, is seen on the left bank of the stream, traversed by seams of quartz and calc-spar, underlying to the NW. 50°. Above this the rock is greenstone, presenting a wall-like appearance, and rising in overhanging cliffs."

Alexander Agassiz. (Proceedings Boston Society of Natural History, Vol. XI, pp. 245, 246, 1867. In continuation of paper quoted *ante*, p. 27.) "The same is the case at the Douglass Houghton Creek, in Section 36, Township 56, Range 33, where the creek winds its way through a deep ravine cut out of the sandstone, and at the junction of the sandstone and trap, falls a depth of 172 feet. The chloritic bed is well developed on the south side of the creek, while the north side is more greenstone, and all along the whole length of the ravine up to the falls, a distance of 1¼ miles, the horizontal beds of sandstone are readily traced, dipping slightly north near the falls and being horizontal at the opening of the ravine into Torch River valley, plainly showing that they rest unconformably upon the trap range. On examining this sandstone more carefully we find that the strata are made up of alternating layers of sandstone of reddish or yellowish grain, and of beds of loose sandstone containing boulders; some of the beds of boulders resembling what is common on sea-shores as a mixture of mud and shingle. On breaking open several of the small boulders taken *in situ* from the beds we find that they consist mostly of reddish trap, but frequently we come across perfectly well waterworn boulders of grayish trap containing amygdules, identical with the trap of the copper range a short distance west from these beds of sandstone, plainly showing that the sandstone was deposited upon the shores of the ridge of trap forming Keweenaw Point, and has not been uplifted by it as is stated by Foster and Whitney. The case is totally different with the sandstone north of the range that lies conformably upon the trap, but the sandstone of the southern side of the mineral range in the vicinity of Torch Lake is plainly of a different age, lying, as it does, unconformably upon the former. I shall be able, I trust, to make a more careful examination of this subject, and by examining a greater number of points the discrepancy between the observations of Messrs. Foster and Whitney and mine may be explained.

Mr. L. G. Emerson, a mining engineer, who examined these points with me, for a long time resident of Ontonagon County, tells me he has observed a similar state of things at the junction of the trap and the sandstone at Forest Falls and in a southerly direction from Minnesota mine on the south boundary of the range, and that he found there the sandstone beds resting unconformably upon the beds of trap dipping north."

Raphael Pumpelly, 1870–'72. (Geological Survey Michigan, Vol. I, Part II, pp. 2, 3, 1873.) "At the western edge of this belt, its nearly horizontal strata abut against the steep face of a wall formed by the upturned edges of beds of the Cupriferous series of melaphyr and conglomerate, which dip away from the sandstone, at angles of 40° to 60°, according to geographical position. This sharply defined and often nearly vertical plane of contact, having been seen by the earlier geologists at several points along a distance of many miles, and having been found to be often occupied by a thick bed of chloritic fluccan, which was looked upon as the product of faulting motion, was considered as a dislocation.

"This idea, seemed to gain corroboration in the fact that, on the western side of

Keweenaw Point, sandstones bearing considerable resemblance to those of the eastern horizontal beds occur, apparently conformably overlying the Cupriferous series. Both sandstones came to be considered as identical in age and as forming the upper member of the group.

"There are many circumstances which make it difficult for us to accept this conclusion. One obstacle lies in the enormous amount of dislocation required, for instance at Portage Lake, where the strata of the Cupriferous series, with an actual thickness of several miles, dip away from the supposed *longitudinal* fault at an angle of about 60°.

"Again, there are at least two patches of sandstone lying on the upturned melaphyr beds near Houghton, though it was not easy to prove that they were not brought thither by glacial action. Mr. Alexander Agassiz informed me that he has found in the horizontal sandstones near this so-called 'fault' abundant pebbles of the melaphyr and conglomerate of the Cupriferous Series, a fact which I found abundantly confirmed on the spot."

M. E. Wadsworth, 1879. (Notes on the Geology of the Iron and Copper Districts of Lake Superior., Bull. Mus. Comp. Zoöl., Whole Series, Vol. VII, No. 1, pp. 115–117.) "It is to be remembered that Mr. Agassiz, in conjunction with Mr. L. G. Emerson, the well-known mining engineer of Hancock, and at one time assistant on Prof. Pumpelly's geological survey, found below the Douglass Houghton Falls pebbles of the melaphyr (amygdaloid) in the sandstone; and from this the conclusion was drawn that the sandstone was younger than the trappean formation. At the time of our visit to this locality, we had no knowledge of Mr. Agassiz's observations, except from the general statement of Prof. Pumpelly. It will be seen that no localities were given by Prof. Pumpelly, although he confirms Mr. Agassiz's statements. The falls were said by Mr. Agassiz to be located at the junction of the sandstone and trap, while on both sides of the ravine the horizontal sandstone beds were traced up to the falls. Our examination showed that immediately below the falls sandstone and conglomerate exist, dipping N. 45° W. 25°. * * * While the majority of pebbles were of the usual character, one grayish granitoid pebble (506) containing epidote was obtained. This has suffered the same *graphic* alteration in its feldspar that No. 527 has. Much of the feldspar is seen to be triclinic. Otherwise than its containing more quartz, its characters are in the main like No. 527. The sandstone, at its junction with the overlying trap, is much indurated and altered, and specimens were obtained showing the junction of the two. * * * As the sandstone underlies the trap, it is of necessity the prior-formed rock. We suppose that this was the locality at which Messrs. Agassiz and Emerson obtained their specimens of melaphyr in the conglomerate. If so, it is easily enough explained, for conformably underlying this sandstone is another sheet of melaphyr, then more sandstone, again more melaphyr, and so on, all conformably underlying one another as much as they do anywhere within the trappean belt, or can do, on account of their origin. Whether this is the spot or not, it is evident from the language of Mr. Agassiz's paper that the gentlemen took their facts and drew their conclusions while they were within the trappean belt, not having found the junction at all, it being some distance below the falls, not at them. From Prof. Pumpelly's statement it would seem that he had made the same mistake, as likewise Mr. Foster had done years before. Something more is necessary to be observed than simply to find a sandstone or conglomerate on the eastern side; it is necessary to prove that it is part of the eastern sandstone, and not a bed intercalated in the trap. The sandstone and melaphyr, a short distance below the dip last given, has a dip of 20°, still inclining to the northwest. The last melaphyr sheet underlies a sandstone dipping at this angle, and is itself underlaid by another sandstone having the same dip. In other words, the last trap on the eastern side of Keweenaw Point is a thin flow of only some 2 feet in thickness, at this locality, and is interbedded between sandstones which immediately above and below it have the *same dip* that it has. As the river is followed downwards the dip gradually declines

in steepness, although still dipping northwest. The last dip measured was N. 45° W. 5°. The conglomerate and sandstone below the first basaltic flow, *i. e.* that nearest to Torch Lake, has apparently been acted upon by hot waters. The sandstone has been leached, its feldspathic constituents largely changed into clay, and the pebbles are greatly altered and kaolinized. The constitution of the sandstone and conglomerate appears to have been originally the same as that of the bands interlaminated with the trap, except so far as they are modified by the detritus of the latter. In many places this hot water action has bleached the sandstone and leached out of it all the argillaceous material, leaving it a nearly pure siliceous sandstone. * * * This has also converted some of the finer beds into a fine-grained, highly argillaceous sandstone or arenaceous clay, these beds having probably arrested the progress of much of the argillaceous material. * * * This water action would certainly account for the absence of fossiliferous remains in the sandstone exposed to its effects. Considerable mica in fine scales was seen in the argillaceous bands. Specimens of the various pebbles were taken from the conglomerate. * * * No. 517 is a grayish and reddish-brown granitoid-looking rock, and under the lens is apparently composed of feldspar holding quartz grains. Microscopically it is seen to be a crystalline aggregate of decomposed feldspar and hornblende, holding much secondary quartz. The quartz is arranged in the feldspar in the *graphic* or eozoön form, which makes the decomposed feldspar a most beautiful object in polarized light. The contrast between the brilliantly polarizing quartz and the feebly polarizing, kaolinized feldspar substance is thus strongly brought out. The quartz appears to have been deposited from the decomposed feldspar itself, which breaks up into silica and the kaolin-like material. The quartz contains full fluid cavities, those with bubbles, and vapor cavities. The hornblende is in the usual reddish-brown decomposed masses. Some magnetite was seen. This rock is most probably a decomposed old trachyte, although it would doubtless be regarded as a granite porphyry by most lithologists. No. 515 is a similar but more feldspathic rock. No. 513 is similar to No. 527, and Nos. 514 and 516 are like No. 524. Many pebbles or lenticular masses of clay were seen, that are apparently decomposed pebbles of the conglomerate."

R. D. Irving, 1880. (Manuscript notes.) "In the afternoon of September 6 we examined the ravine on Sec. 31, T. 56, R. 33 W., in company with Mr. L. G. Emerson, of Hancock, with the object of seeing something of the unconformable junction described by Pumpelly as obtaining here between the Eastern Sandstone and the Keweenaw Series. The Douglass Houghton Fall, at the head of the ravine, is over the ordinary diabase-amygdaloid, with the ordinary northwesterly dip that prevails from here all across the Keweenaw Series. Below the fall the trappean beds are badly shattered and decomposed. About 100 paces below the falls, on the south bank, well up towards the top, sandstone layers with included shale and conglomerate were seen dipping to the northwest, or towards the trap, about 30°. The exposure is poor, and largely covered with clay and fallen material from above. Decomposed, ill displayed ledges of trap show within 20 feet of the sandstone. Seventy paces farther down stream, also on the south side, similar layers were seen with a similar dip, and again about 40 steps farther down on the north side of the stream. These ill concealed, northwesterly dipping layers seem to be tumbled and out of position. The pebbles in the conglomerate seem mainly to have been derived from some of the acid members of the Keweenaw Series. Below these inclined layers, for several hundred paces, following the south bank, we saw nothing in the way of satisfactory exposures of the sandstone, which was, however, seen here and there projecting from the bank, or in the stream bed in fallen masses. But at about 300 steps down we found horizontally placed layers of the ordinary white quartzose sandstone, with interstratified conglomerate seams, in which pebbles were found not only of some of the acid, but also of the basic rocks of the Keweenaw Series. Query: Are the dipping layers near to the traps part of the Keweenaw Series or part of the Eastern Sandstone?"

W. M. Chauvenet, October 25, 1880. (From manuscript notes.)[1] "Starting at the Falls of Douglass Houghton River, the course of the stream, which was in general easterly, with some turns to the southeast, was followed 1¼ miles.

"Crumbling trap extends some 60 to 70 paces down from the falls.

"About 125 paces down-stream, on the south bank, conglomerate and sandstone show in a few streaks high in the bank, dipping NW. 30° to 40°, but much fallen and decomposed.[2]

"Seventy paces farther down similar conglomerate and sandstone, in all about 5 feet in thickness, were seen in the north bank. The section here seen is: Sandstone, 2 feet; conglomerate, 2 inches; sandstone, 1 foot; conglomerate, 2 feet. The strike of these layers is N. 38° E.; their dip 25° to the NW.

"Thirty paces farther down, also on the north bank, similar layers, dipping similarly to the NW. 25° to 30°, are exposed on a larger scale, there being here seen, with some interruption, a thickness of over 100 feet.[3] Quite similar layers are also exposed a short distance below, on the south bank, and again 30 steps farther down, on the north bank, where the position is again substantially a horizontal one.

"Three hundred and fifty steps farther down stream, a heavy layer of white sandstone shows in the south bank in a general horizontal attitude, but presenting a slight, wavering dip in different directions. In the creek bed here conglomerate shows.

"Three hundred and sixty-five steps farther down horizontal layers of sandstone occur in the south bank; the area of the exposure being 20 by 30 feet.

"One hundred steps farther one or two small exposures of a sandstone show, dipping slightly toward the south.

"One hundred steps farther both banks of the ravine show thick layers of sandstone, dipping 2° to 5° SE.

"Similar layers show, with a thickness of 50 feet, on both sides with a similar dip.

"For the rest of the distance, down to the low land of Torch Lake, the sandstone shows in a general horizontal attitude, with a tendency to dip slightly in different directions.

R. D. Irving, 1880. (Copper-Bearing Rocks of Lake Superior. Monographs United States Geological Survey, Vol. V, p. 355.) "The occurrences on the Douglass Houghton River are much like those seen on the Hungarian, with the exception that the true Keweenawan beds extend down stream for some 300 paces from the head of the ravine, for the reason that they include just here a considerable thickness of soft conglomerate. Below the last of these beds is a gap of some 200 paces, when the horizontal layers of the Eastern Sandstone come in, here and there with a slight northwesterly dip (2°–5°), but more often with a southeasterly one. These conditions obtain for a mile or more down the stream. Mr. Wadsworth has also described the exposures on the Douglass Houghton River, and correctly, so far as showing, which he was the first to do, that the conglomerate for some distance below the falls does not belong with the Eastern Sandstone, but is really interbedded between diabases of the Keweenaw Series. When he represents, however, the sandstone still farther down stream as passing beneath the last Keweenawan diabase he bridges in his imagination a covered gap of several hundred paces, beyond which, to the eastward, the sandstone lies flat, or inclines varyingly and indifferently slightly to the

[1] Mr. Chauvenet's MS. is mainly in the shape of detached and abbreviated notes with reference to a diagram of the course of the ravine which is not here reproduced. In transcribing them we have added some words to fill out the meaning, but no statements are given that are not in the original. The locations will be understood from the chart of Plate XII.

[2] This is the exposure A of Plate XII.

[3] This is G of Plate XII.

northwest, southwest, or southeast, not showing any sign of a persistent and gradually decreasing northwestern dip. Were this ravine the only place where the Eastern Sandstone could be seen in proximity to the north dipping Keweenawan beds, and were there not other considerations rendering such a conclusion untenable, the idea that Mr. Wadsworth has advanced might perhaps suggest itself as a possibility, although so far as the exposures here are concerned it could be nothing more. There would remain even then, as looking the other way, a marked lithological difference between the intercalated sandstone and that farther down the stream; the latter being a much more purely quartzose rock, while at the same time containing pebbles of the porphyry, whose detritus composes the usual interbedded sandstones of the trappean series."

C. Rominger, 1883. (Manuscript notes.) "In Torch Lake Creek I commenced the examination on top of the range above Douglass Houghton Falls, where I saw the creek flowing through a channel across a large series of alternating massive and amygdaloid diabase belts before it fell down over a precipitous escarpment of similar diabasic and amygdaloidal belts, which I estimated to have a height of not less than 100 feet.

"The dip of the diabasic beds is about 40° to the northwest. Below the falls a large body of amygdaloid rock, in a much shattered, brecciated condition, recemented apparently by sedimentary material, forms the bed of the creek flowing in rapids.

"Below this amygdaloid follows a very large succession of arenaceous beds, in alternation with conglomeratic seams, inclosing porphyritic, diabasic, and amygdaloidal pebbles, which dip in conformity with the overlying diabase belts northwest and at about the same angle.

"Some of these sandstone layers being rather light colored, mostly composed of quartz grains, and comparatively soft, resemble very much the Eastern Sandstone; other beds again are harder and darker red-colored. A narrow belt of diabasic nature, which is indicated by Wadsworth as being interstratified with this series, I could, in spite of all my attention in crossing the series, not discover.

"These beds, exposed in the steep sides of the ravine for a long distance downward, retain their dip to the northwest without an obvious diminution of the angle, until we come to a place where the stratification is totally obscured, and the masses forming the slope of the hillside are an orderless rubbish of soft sand rock, mingled with dispersed pebbles. Also in the creek-bed for awhile no exposure of rock beds in place is visible, but not a long way farther down, the bottom of the creek is formed by horizontal layers of sandstone, while the sides are yet formed by the rubbish-like masses; but soon after, also in the sides of the ravine, well stratified horizontal sandstone ledges make their appearance, and continue all the way down to the flats bordering Torch Lake.

"Of a gradual diminution of the dip of the sandstone layers, until their position has almost become horizontal, as Mr. Wadsworth asserts, I could not see the least sign; on the contrary, the change is perfectly abrupt; the layers dipping northwest are separated from the horizontal ones by a space covered with rock masses, in which no dip is recognizable. I unhesitatingly consider the group of sandstone and conglomerate beds dipping in conformity with the trap belts as actually underlying rocks, making part of the copper-rock group, although, considering their lithological character alone, I would have united them with the Eastern Sandstone."

J. D. Whitney and M. E. Wadsworth, 1879. (The Azoic System. Bull. Mus. Comp. Zoöl., Vol. VII, No. XI, 1884, pp. 482–485.) "The copper-bearing rocks of Lake Superior have been considered by some geologists as a distinct formation, older than the Potsdam sandstone, adjacent to which it lies. The principal evidence in support of this opinion was supposed to have been obtained at the falls of a branch of Torch River, known by the name of Douglass Houghton. Here the trappean or cupriferous series was said to end, and to have abutting against its edges strata of the Potsdam. The latter was also said to contain fragments of the other, necessarily older, rock,

These facts were thought to prove that the copper-bearing rocks formed a sea-shore bluff, along the base of which the sandstone was deposited with its trappean fragments. In order that the reader may understand the condition of things at that point, it will be necessary for us to indicate the structure of the copper-bearing rocks themselves. They consist of a series of old lava flows (diabase and melaphyr), intercalated between beds of conglomerate and sandstone. The traps are known to be lava flows, by the baking and induration of the immediately underlying rock; by the fact that tongues and dikes extend from the overlying trap down into the rock beneath; by the scoriaceous character of the upper portion of the traps, and the coarser crystallization of their lower parts; by the macrocsopic and microscopic evidences of flowing, etc. That they in each case were *in situ* before the immediately overlying rock was deposited, is shown by the facts that they have not affected it in any way, and that they present on their upper surface the irregularities and rounded knobs which lava flows are known to have, especially when exposed to water action; by the presence of rounded fragments of the underlying trap inclosed in the overlying conglomerate; by the absence of fragments of the overlying rock in the underlying one, and by the absence of any marks of intrusion of the traps between different beds.

"Sometimes the lava flow was followed by another, without any apparent long exposure of the former; then again the interval between the two succeeding flows was so great, that sandstones and conglomerates having a thickness of from a few inches to half a mile (Marvine), were deposited between them. Of course from this it followed that the surface of the underlying trap suffered denudation, and that afterwards the conglomerate was deposited unconformably upon it. This was the general mode of formation throughout the series on Keweenaw Point. The general condition of things may be correctly indicated by the statement, that in going from the east towards the west the cupriferous series is found to be made up of an increasing number of lava flows and a diminishing number of conglomerates, until a point is reached where the volcanic activity culminated, when the flows diminished and the conglomerates increased, until the Western sandstone was reached. It would follow from the mode of formation, that whenever a sandstone or conglomerate was laid down on the trap, denudation of the latter would take place and fragments of it be inclosed in the unconformably overlying detrital rock; and this would hold good not only of the intercalated beds, but also of the Western Sandstone. All these evidences of denudation would then be merely signs of sequence of time, and not of a difference in geological age. Precisely similar facts may be observed at the present day wherever a lava flow has an opportunity to reach the shore of the sea.

"The question, then, whether the copper-bearing rocks are a formation of a geological age older than the Lake Superior Sandstone is to be ascertained, if at all, on the eastern, and not on the western side. It has just been pointed out on what evidence the Eastern sandstone was said to be younger than the traps; but a careful examination of the region in question showed its incorrectness. At the Douglass Houghton Falls the stream passes over a cliff of trap, and then winds through a gorge having high and very steep banks. It was very natural that, in ascending this stream from Torch Lake to the Falls, the hasty observer should be led to believe that the sandstone and conglomerate extend in an unbroken band up to the cliff at the latter locality, and regard it as an old sea-shore bluff. This would especially be the case should he confine his observations to the stream, and not attempt to explore the clayey, slippery, difficult sides of the ravine. The writings of previous observers give no evidence that they did more than to follow the bed of the stream; and they all concurred in stating that the sandstone was horizontal, or nearly so, up to the Falls, at which place the trap was said to be first met. When Dr. Wadsworth examined the locality in 1879, he not only explored the bed of the stream, but also the bluffs on both sides. These examinations showed that the sandstone and conglomerate were not horizontal, but that they had a gradually increasing dip as the Falls were approached from 5° up to 25°, while on both sides of the stream the traps were

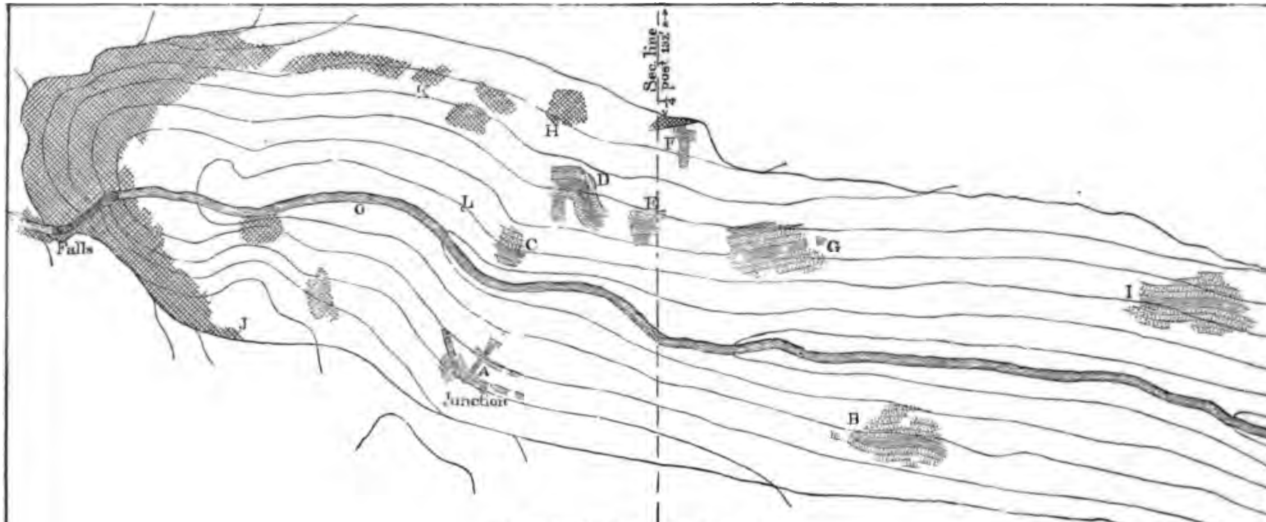


Fig. 1.- Plat of Exposures.

Fig. 2.- Generalized Section showing Structure.

JUNCTION OF THE EASTERN SANDSTONE AND THE KEWEENAW SERIES, DOUGLASS HOUGHTON RAVINE

Scale · 1 inch=150 feet. Contours, 20 feet vertical distance. Top of map to the north.

: holding the same relations to the sandstone and conglomerate that they have stated to hold elsewhere in the series. These traps had been masked and con- l by the falling rock and earth; but, on digging, foot after foot of the junctions umber of the lava flows and their adjacent sandstones were exposed. The flow st Torch Lake is about two feet in thickness, lying between two beds of sand- , all having a dip of 20°. Junctions of these beds and the flow were exposed by ating along a distance of about twenty feet. The trappean pebbles seen by r observers at the Falls were seen to have been derived from the underlying trap, y are throughout the entire series, and not from the supposed old sea-shore bluff. e same way, the sandstone and conglomerate were carefully followed up by the arian River from Torch Lake, and the same condition of things observed. hese observations are of a kind to exclude any probability of a mistake; they are and definite. Moreover, they explain the errors of previous observers, and until d, if they can be, they conclusively show that the Eastern Sandstone and the r bearing series are one and the same geological formation, although differing ie sequence. It is a remarkable circumstance, that, while this evidence is so and explicit, the more recent writers have carefully avoided any mention of it, ave endeavored to discuss the subject on theoretical grounds chiefly."

id., p. 563.) "Since the first part of this work was put in type, another report on eology of Keweenaw Point has been published by Professor Irving, in the Third al Report of the Director of the United States Geological Survey. The state of nowledge up to the time of the casting of that portion of the work has been ited. * * *. In Irving's report the before-mentioned observations * * * adsworth at the Douglass Houghton Falls are accepted and pronounced cor- n every particular but one. Irving then acknowledges that the copper-bearing are continuous with the Eastern Sandstone below the falls; but in order to e the dilemma in which this places him, he says that below on the stream is a ed space between the true Eastern Sandstones and those which every previous ver had called such, and that here is the junction between the sandstone and enawan Series. This space he said Wadsworth had bridged over in his imag- n. To this the latter replied, 'that, by digging in the stream and on the banks ravine, he had actually traced (not imagined) the relations of these rocks, from those dipping 5 degrees up to those dipping 25 degrees, and that they were o form a continuous super-imposed series, no such cliff as imagined [by Irving] ng between them.'"

llowing the Douglass Houghton ravine upwards from the lowlands t Torch Lake we found the sandstone, of the usual quartzose type, cting frequently from the sides of the ravine in larger or smaller sures, which, for a long distance from the mouth of the ravine, show ssential horizontality of the layers. Subordinate to this horizon- , however, is a gentle bowing or curving structure, by which the s often from 2° to 5° in different directions. Thus dips of this nt were measured in northwest, southwest, and southeast direc- . As the ravine is ascended, the exposures show more interstrati- soft, shaly matter, which becomes conglomeratic with well-rolled les of the various Keweenawan eruptives, chiefly of the acid type, y no means to the exclusion of the basic kinds. The sandstone lay- nterstratified with these red shaly conglomerates vary from white to ish-white in color, according as they are more purely quartzose or ain an admixture of the red clayey material which is the main tituent of other layers. This sandstone is commonly quite friable

and loose, but again is often very considerably indurated locally. The induration, as is suggested even by the appearance to the naked eye and as is demonstrated by the thin section, is a quartzose one, the infiltrated quartz having built out the fragments into interlocking areas. The first point in ascending the stream at which we noticed the interstratifications of sandstone and red shaly conglomerate is about 450 steps below the junction of the Eastern Sandstone and Keweenaw traps, as subsequently described. Below this we traversed a considerable interval without good exposure. At this point a white layer of sandstone overlies 20 feet or more of the shaly conglomerate on the south bank of the ravine. It is evidently the place noted by Mr. Chauvenet in the quotation above given.

From here up-stream for 300 or more paces, or to within 150 steps of the junction with the trap, we found the essentially horizontal position of the sandstone and interstratifications with shale and shaly conglomerates continuing. After this, however, more marked disturbances in the sandstone begin to display themselves. At about 100 steps below the junction, on the north bank (point G of the topographical sketch of Plate XII), a large face of the conglomerate and shale shows, having been laid bare by a slide not many years old. The exposure here is 28 steps in length along the face of the bank and shows layers in all about 100 feet or more in thickness. Here the shaly conglomerate is in large proportion compared with the sandstone, which appears in a few comparatively thin layers. The inclination is as much as 25° to 30° to the northwest, while only a short distance down stream on the other side of the ravine the layers are essentially horizontal (B of Plate XII).

Continuing now along the north bank of the ravine we come, within a few steps, to a succession of slides, evidently of very recent date, between which there remain spaces still covered with trees and bushes. The first of these slides reaches nearly to the top of the ravine. Here, immediately below the top of the bank (F of Plate XII), we found the conditions represented in Figure 4. Just below the top of the bank

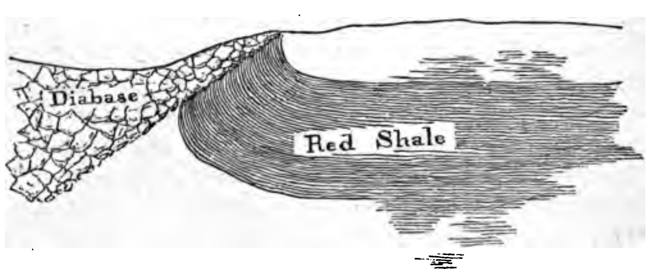


FIG. 4.—Junction of a member of the Eastern Sandstone and Keweenawan diabase, Douglass Houghton Ravine, Keweenaw Point, Michigan.

there remains here a portion of the trap or diabase, immediately beneath and in immediate contact with which are red, for the most part *non-conglomeratic*, shales, the layers of which present edges having an

upward curvature from a horizontal position as they approach the contact with the trap. Extending downward from this junction for about 50 feet, we dug a trench with a view to determining more definitely the position and composition of these layers than we could do from the mere surface exposure. We found them for the length of the trench to hold but few pebbles and but one interstratified sandstone layer. The inclination within the trench we found to be 12° slightly to the east of north, or into the bank. Farther down this slide sandstone projects in the usual massive layers, interstratified with shale and conglomerate, but so badly covered with the débris from above that we could not determine satisfactorily the position. A short distance to the west and somewhat farther down the bank, however, on the other side of a tree-covered projection, we found these same layers better exposed and inclining slightly to the northwest (E of Plate XII).

A few steps farther to the west, following these inclining layers, we found the very interesting exposure marked D on Plate XII. The layers of this exposure are not visibly continuous with those of the preceding one, there being a few feet intervening where the rock is concealed; but that they are exactly the same layers is manifest from their entire similarity in character and interstratification. The position of the layers here is represented in Figure 5, which is sketched from a

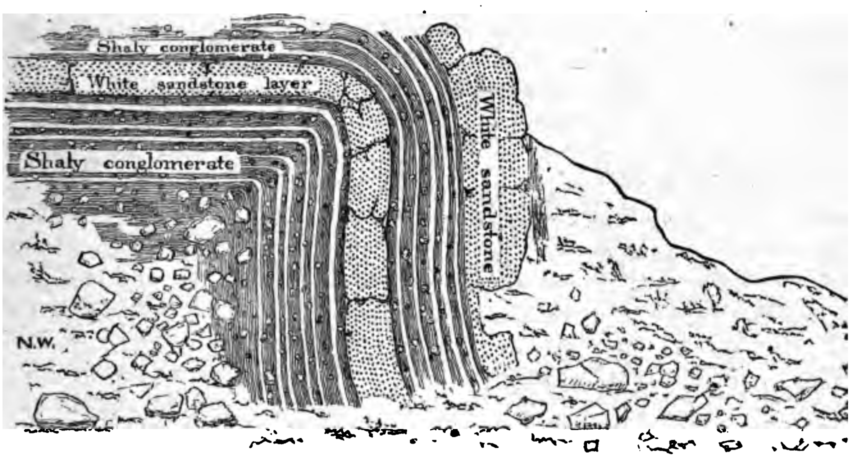


FIG. 5.—Bend in the Eastern Sandstone, north side of Douglass Houghton ravine, Keweenaw Point, Michigan. Scale, 20 feet to the inch.

photograph taken by us. The entire thickness of the layers visibly affected by this singular bend is as much as 30 or 40 feet. Vertically above this exposure, but separated from it by a considerable space covered with trees and fallen material, in which we vainly dug to find a junction, large masses of trappean material show up to the top of the ravine (H of Plate XII). This trap is continuous with the remainder of the Keweenawan exposures up to the falls and beyond. From the

position of the sandstone exposure at C, where the material is mainly white silicious sandstone, with but little interstratified shaly material, it is evident that the junction of the sandstone with the trap is some distance farther west at the bottom of the ravine than at the top. But here again the same tree-covered depression baffled our efforts towards uncovering the exact junction. At the point L we dug a pit, which disclosed sandstone of the same character as at C, and immediately above and to the west uncovered trap; but we did not feel entirely confident that the latter was in place.

However, just across the ravine from the projecting point at C we noted, at a considerable elevation in the bank, and partially uncovered by an old slide, exposures of sandstone, shale, and trap in such proximity as to promise the finding by digging of the exact junction. The exposures here (point A of the plat of Plate XII), and the positions of our trenches are shown in Figure 6. Beginning at the covered

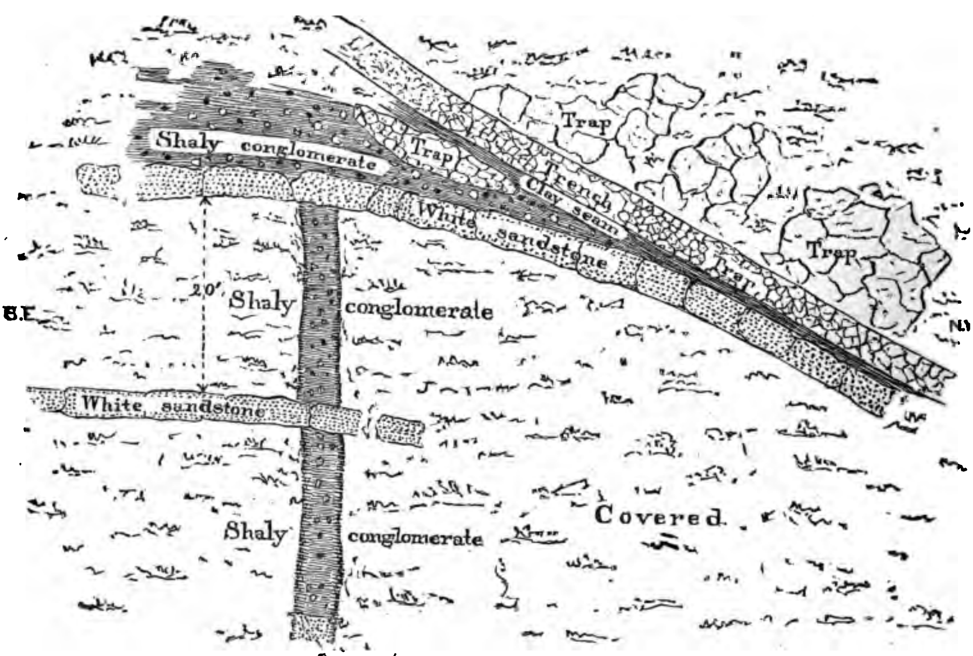


Fig. 6.—Junction of the Eastern Sandstone and Keweenawan diabase, south side Douglass Houghton Ravine, Keweenaw Point, Michigan. Scale, 20 feet to the inch.

space on the east side of that portion of the slide represented in the wood-cut, we noted portions of two of the white sandstone layers, similar to those seen on other exposures, lying about 20 feet apart on the slope of the bank. Each of these layers is about three or four feet thick, is composed in the main of silicious material, and is affected in each case by an irregular but at times a very considerable degree of induration. Each of the layers, as seen on the face of the bank, shows a nearly

horizontal position, but on closer inspection is found to dip slightly into the hill, the exact direction of the dip being about westward and the inclination ranging from 2° to 5°, the smaller angle having been observed at the easternmost ends of the layers. On each side of the uppermost of these layers we found exposures of the usual conglomeratic red shale, the pebbles coming wholly—as we satisfied ourselves by opening many on the ground and studying subsequently a number of thin sections—from the eruptives of the Keweenaw Series, some of them being indistinguishable from traps *in situ* farther up this same ravine. Following these sandstone layers westward, we noted them rapidly increasing in westward inclination, the angle at 20 to 25 feet from the beginning being 12° and at 50 feet as much as 20°. The uppermost of the two layers was then traced, partly by natural exposure and partly by being uncovered, to the junction with the trap, as shown on the sketch, where it was found to incline to the northwestward at an angle of 30°, or not far from parallelism with the bedding structure of the traps themselves. With the aid of a force of miners we uncovered this junction very thoroughly. At the point of the sketch where the uppermost of the two sandstone layers described passes beneath the trap, we uncovered, immediately above the sandstone:—(1) about six inches of soft red clay, including shattered and angular masses of amygdaloid; (2) much altered and fissured amygdaloid apparently in place, about one foot; (3) the non-amygdaloidal trap, very much and irregularly fissured. In the amygdaloid was noted a tendency to a schistose structure parallel to the red-clay seam at the junction. Following this clay seam up the bank with our trench, we found it soon departing from contact with the white sandstone and traversing obliquely the red shaly conglomerate immediately above that sandstone layer, and a little farther leaving below it a mass of the trap ten feet in length by four in width. This mass is badly decomposed, is affected throughout by a strongly marked schistose structure parallel to the clay seam, and shows along its sides and along the fissures which produce the schistose structure shining "slickensided" surfaces. Carrying the trench still farther in the same direction we soon reached the drift material forming the upper part of the bank, and after a good deal of digging here, with the hope of carrying the junction still farther, we concluded that we had reached the original sub-drift surface. Turning our attention next to the other end of the trench, we carried it down the hill until the detritus and material from above were too heavy for us to remove. We were thus unable to reach a point at which the junction should leave the sandstone layer and pass on to the next broad conglomerate beneath it, which it was evidently soon about to do. From the last point reached we ran a trench some ten feet down the bank, in which we found the layers of red shaly conglomerate conforming in position in a general way to the sandstone at the junction but lessening in amount of westward dip as we carried the trench downward. Returning now to about

the middle point of the slide we ran a long trench from the upper one of the sandstone layers down the bank, in all some 40 feet, uncovering continuously the soft red conglomerates interstratified with the harder sandstone layers, and just reaching at the bottom of the trench a third sandstone layer. Throughout this trench the inclination of the layers is uniform, being slightly westward, or into the hill.

Before proceeding to notice the exposures above the junction of the sandstone and trap, we wish to speak somewhat more definitely with regard to the lithological characteristics of the sandstone series. So far as the exposures in this ravine are concerned this series may be described as a succession of alternations of quite white to red, much indurated to friable, moderately heavy, nearly purely silicious sandstone layers and thinly laminated red layers of a shaly or clayey conglomerate. The sandstone layers (which in portions of the thickness are greatly subordinated to the softer conglomerate layers, while in other portions equaling or even exceeding the latter in amount) are often nearly white, but more frequently are somewhat tinted with brown or red. The thin sections show them always to be composed in great preponderance of quartz fragments, mingled with which in subordinate quantity are fragments of feldspars and of felsitic material, and fragments referable to the basic members of the Keweenaw Series. There is also more or less red oxide of iron mingled with a clayey decomposition-product, which is most abundant in the least indurated and most deeply colored varieties. The induration varies greatly in amount and occurs irregularly with regard to any one layer, the layers in which the strongest indurations were noted being those interstratified with a large proportion of the shaly conglomerate. This induration evidently bears no relation to the proximity to the junction with the traps, having been noted at various horizons and places distant from as well as near to the trap, while the sandstone found actually at the contact was often but little indurated, and in no place markedly more so than noted in the case of certain layers many feet below the junction. In all the thin sections of sandstone examined, covering in some measure each of the exposures mentioned, the induration of the rock when present was seen plainly to be due to a quartz infiltration, the original fragments having received enlargements sufficient to make the areas interlock to some extent. This is a form of induration wholly independent of igneous agencies, and is one which we have observed carried out in a high degree in undisturbed sandstones many miles distant from any known eruptive material. The only exception to the induration by quartz is met with in the presence, in certain sections from layers close to the junction with the trap, of a notable quantity of crystalline calcite. This calcite occurs in addition to the indurating quartz and not to its exclusion.

With regard to the softer conglomeratic layers of the sandstone series, *it is to be said that* their matrix, while mainly clayey, varies between

phases where it appears to be nearly pure clay and others where there is a notable proportion of arenaceous matter mingled with the clay. As to pebbles, these layers vary from those in which the pebbles are quite small, one inch and less across, to others in which they are good sized bowlders. These coarse bowldery deposits are quite strikingly shown in the slide on the southern side of the ravine, between 300 and 400 feet below the junction with the trap (exposure B of plat of Plate XII). Here we have a notable expression of the entire lack of assortment which is still more prominently shown on the Hungarian Ravine, as described below, the coarse pebbles or bowlders being quite irregularly disposed throughout a fine clayey matrix. There is no approach to a definite classification of coarse and fine material and the gathering of each into nearly homogeneous beds that usually takes place in the deposition of such layers. As to the nature of the pebbles and bowlders of these layers, our examinations on the ground and our study of specimens in thin section warrant us in saying that they are almost wholly, if not wholly, referable to the eruptives of the Keweenaw Series, both acid and basic. It is not necessary for us to go into any detailed descriptions of these pebbles. We may merely say that our thin sections prove them to include felsites and felsitic porphyries, granitic porphyry and peculiar granitoid rocks, indurated (silicified) diabases, little altered diabases, and fragments of amygdaloid, plainly recognizable as belonging to the peculiar Keweenawan types, for descriptions of which we must refer the reader to other works.

Turning now our attention to that portion of the ravine above the junction, we have to note in the first place that nearly all of the way up to the falls the exposures, while nearly continuous on one or other side of the ravine, show much shattering; the confused appearances produced by which have been enhanced by considerable decomposition, and by the slipping along the very steep sides of the ravine in great slides of much of the shattered material. On a careful examination of both sides of the ravine, however, these exposures showed us nothing but some of the usual eruptives of the Keweenaw Series, for the most part diabases and amygdaloids, with the usual northwesterly dip, here about 25°, as seen very distinctly on the beds at and above the falls. At the point J, near the top of the south bank, a felsite or quartz porphyry occurs, and a corresponding rock is met with on the opposite side of the stream in a proper position, considering the dip and strike of the beds, to be part of the same layer. The occurrence of this rock here, first observed by Mr. W. N. Merriam, is a point of considerable interest. The layer or bed of felsitic porphyry whose existence here is thus indicated seems to be the same as that which makes quite a broad exposure on the line of the Hecla and Torch Lake Railroad, in the southern part of section 36, as already described by one of us in another place.[1]

[1] Monographs United States Geographical Survey, Vol. V, p. 196.

Our reading of the structure indicated by the exposures along this ravine is given in Figure 2 of Plate XII, our conclusions being that the sandstone is altogether newer than the Keweenaw Series, whose fragments it contains so plentifully; that the present line of contact shown on this ravine is a fault line; and that the bowed and, at the contact, crushed condition of the sandstone is due to the faulting. The arguments upon which these conclusions are based are given more fully in the general discussion at the end of this paper.

It remains for us to examine the already quoted descriptions of earlier observers, that we may see how far their statements may be reconciled with our own, and that, in so far as they cannot be so reconciled, we may give our reasons for declining to accept them.

In Mr. Foster's account, which is for the most part of so general a nature as to be reconcilable with quite discordant detailed descriptions, there are yet two or three statements with which we cannot at all agree. In speaking of the pebbles of the conglomerates here exposed as "for the most part of white quartz," he is certainly wrong. Such pebbles may occur, but after breaking open a large number of pebbles at various exposures, we failed to discover any such. He is also as certainly wrong in saying that the sandstone rests "on the trap in large blocks, 70 feet above its bed." The only possible warrant for any such statement, so far as we were able to see, consists in the occurrence of trap in the stream-bed, and, some little distance to the eastward, of sandstone high in the bank. In speaking of the sandstone as dipping southerly near the junction, he certainly states what is true, but it is equally true that in the same vicinity it lies horizontally and dips in various other directions. Upon these statements of Mr. Foster are based, we suppose, those quoted above from Foster and Whitney's joint report. The latter do not seem to call for any additional remark.

In Mr. Agassiz's description, except in one or two minor points, we find nothing with which we cannot agree. All that he says with regard to the general horizontal position of the sandstone, subordinate to which are variations from horizontality, and with regard to the nature of the sandstone and conglomerate, coincides with our own observations. In comparing the conglomerate beds to the mixtures of "mud and shingle" met with on sea shores, Mr. Agassiz notes what is perhaps the most interesting feature of these conglomerates, viz, the singular lack of any assortment of the materials composing them. In speaking of the falls as *at* the junction of the trap and sandstone instead of as at some little distance above that junction, it seems evident that Mr. Agassiz is speaking in a general way only, since he speaks in the same connection of the chloritic bed of Whitney and the other traps as showing on the sides of the ravine below the falls.

Professor Pumpelly's statements being, so far as they refer to this ravine, merely confirmatory of those of Mr. Agassiz, do not require any

especial attention in the present connection. We may merely say, with regard to the "chloritic fluccan" (since it seems evident that by this expression they cannot have referred to the red shaly débris which, as subsequently shown, we have uncovered by excavating along the junction with the Eastern Sandstone at various points) mentioned by both of these gentlemen (following the earlier geologists) as occurring at the contact between the sandstone and the traps, that it appears to us to be nothing more than a shattered and somewhat altered condition of the trappean beds themselves. It will be seen hereafter that we regard this shattered trappean material as the result of faulting motion, thus far dissenting from the position taken by Messrs. Agassiz and Pumpelly.

Not stopping now to discuss the statements in the above given quotations from Messrs. Whitney and Wadsworth as to the general condition of things in the Keweenaw Series, in which statements we find much with which we cannot agree, we note, so far as the Douglass Houghton ravine is concerned, three principal points in which their descriptions conflict with our own. These are: (1) as to the inclination of the sandstones below the junction; (2) as to the interstratifications of traps and sandstones at the junction; and (3) as to the non-occurrence of trappean pebbles in the sandstone below the last trappean bed.

According to Mr. Wadsworth, his "examinations showed that the sandstone and conglomerate were not horizontal, but had a gradually increasing dip, as the falls were approached, from 5° up to 25°." This statement is several times repeated, but after a very careful examination of both sides of the ravine throughout nearly all of its length we feel entirely safe in saying that no such gradually increasing northwestern dip exists. Northwestern dips are seen, as we have shown above, and sometimes at a considerable angle, but the condition of the whole sandstone series is a bowed one, and the northwestern dips are but local, being replaced in each instance within a few feet by inclinations in other directions or by an entire lack of inclination. Moreover, as above shown, between those points which present the steepest northwestern dips and the junction with the traps, exposures occur in which the sandstone layers are horizontal, and the changes from steep inclinations to horizontality are most strongly marked at the contact of the two formations. In these statements, which we make after the most careful examinations and with full realization of the controversial nature of the case, we find ourselves confirmed more or less completely by the accounts of Messrs. Agassiz, Pumpelly, Chauvenet, and Rominger.

A still more important discrepancy between Mr. Wadsworth's descriptions and our own lies in his statement that at the junction of the sandstone and trap the two formations exhibit a series of interstratifications. As to this Mr. Wadsworth's reiterated statements are so exceedingly definite—except with regard to the exact positions of the interstratifications on the ravine and their exact number, which points are

unfortunately left vague—that we fully expected to find such interstratifications without any difficulty. We knew that in 1880 Mr. W. M. Chauvenet, with Mr. Wadsworth's descriptions in hand, had made a diligent attempt to find these interstratifications without success, but notwithstanding this we could not help feeling that such definite statements as Mr. Wadsworth's must have a substantial basis in fact. After a most careful search for them, however, with the aid of a company of skilled miners, and after two days' work on both banks of the ravine, we failed entirely to discover any such interstratifications as Mr. Wadsworth describes. Since this has been the experience also of Messrs. Chauvenet and Rominger, both of whom made examinations with this special point in view, we cannot but feel that we are warranted in discrediting the existence of these intercalations of trap and sandstone. Of one thing at least we feel entirely confident, viz, that whatever interstratifications of sandstone and trap may here exist are in no sense interstratifications of the Eastern Sandstone with the Keweenawan traps. If they exist at all, they lie above the junction of the easternmost trap with the Eastern Sandstone, or in other words are included within the Keweenaw Series. After uncovering thoroughly the junction of trap and sandstone at the point A of the plat of Plate XII, we made our search for interstratifications of trap and sandstone both above and below this junction, and subsequently Mr. W. N. Merriam made independently a minute examination of both banks of the ravine, at all levels, to the west of the westernmost sandstone exposures, with no more success than we met with. Below the junction at A of Plate XII, we call everything the Eastern Sandstone, and feel confident that there are no trappean beds. To the west of that junction and up to the falls we have seen nothing to suggest the existence of interstratifications of detrital material with the traps, but, since there is here much confusion and much fallen material, we are unwilling to assert positively that no such interstratifications exist. If detrital beds do exist above that point, they are quite certainly wholly different in nature from the beds of the Eastern Sandstone, being either igneo-detrital rocks of some sort or the usual non-quartzose sandstones of the Keweenaw Series. How Mr. Wadsworth may have been misled as to this, we cannot say. In the junction sketch of Fig. 6 it is shown that the joint clay, lying between the sandstone and the overlying trap in our long trench, passes, as it is followed upwards, above a detached and "slicken-sided" mass of trap. Possibly, when ill exposed, such a mass of trap, with red joint clay on one side of it and the red conglomerate of the Eastern Sandstone on the other, might be mistaken for a continuous bed of trap included within the sandstone. It is also possible that in a hasty observation one might mistake the indurated sandstone layers, here seen to be interstratified with soft conglomerates, for trappean beds; but it is difficult to believe that Mr. Wadsworth could have been misled in either of these ways.

A third point of difference between the statements of these gen-

tlemen and our own lies in the matter of the occurrence of trappean pebbles within the sandstone below the junction, they holding that none of the basic eruptives of the Keweenaw Series are represented in the Eastern Sandstone below — or to the east of — its junction with the traps. In their arguments as to the structure here obtaining, this lack of basic pebbles in the Eastern Sandstone below the junction forms an important point, since they regard it as going to confirm their view as to the inferior position of the Eastern Sandstone in relation to the entire trappean series. It is to be observed, however, that even if we admit this absence of basic pebbles no such conclusion can follow, for of all the other classes of pebbles described by Mr. Wadsworth as actually occurring here there is not one that does not represent some acid rock which occurs abundantly in the Keweenaw Series and which has as yet *been nowhere recognized outside of that series in the entire Lake Superior region.* At the time that Mr. Wadsworth wrote the descriptions of these pebbles he seems to have been unacquainted with the fact that they represented rocks which occur in original masses as important constituents of the Keweenaw Series. One of the acid rocks plentifully represented among these pebbles occurs in the Keweenawan in this immediate vicinity. Moreover, as we have said above, the basic rocks of the Keweenaw Series *are* represented by pebbles in this conglomerate quite plentifully, as we satisfied ourselves on the ground and by studying thin sections of the specimens subsequently; and this not merely in the immediate vicinity of the junction with the trap, but at other exposures within 100 to 300 paces below the junction. We have shown above that on Bête Grise Bay the pebbles of the conglomerates, wholly of Keweenawan derivation, are predominantly of the basic kinds. Here, on the other hand, they are mainly of the acid varieties. On Bête Grise the pebbles of the conglomerate are very noticeably angular, while here they are well rounded. Between these two facts we think there is a connection, and conceive that basic pebbles are relatively less abundant on the Douglass Houghton Ravine, because of the greater amount of attrition the fragments have had here. The acid rocks and the highly silicified basic fragments would of course stand such attrition much longer than would the softer diabases and amygdaloids.

In still one other point our description of the Douglass Houghton ravine differs from that of these gentlemen. At the contact of the sandstone and trap they speak of the former as much indurated, regarding this induration as proving the subsequent formation of the trap. So far as our own observations extended, there is always a soft clay, which we look upon as a joint or fault clay, between the sandstone series and the trap at the junction, an observation which entirely coincides with those made by us at each of the other localities at which we examined the contact of these two formations. Disregarding this joint clay, we find at the contact in one part of its extent on the south side of the Douglass Houghton Ravine a soft shaly conglomerate of the East-

ern sandstone series, and in another part, one of the harder sandstone layers; while on the north side of the ravine there is a contact with a soft non-conglomeratic shale. Even the hard sandstone layer, however, is no more indurated than portions of certain other layers, distant from the junction. Indeed, there is distinctly less induration here than at some of the latter points. Even if this were not the case, and the induration at the contact were relatively great, we should not regard it as necessarily proving the relative recentness of the trap. The induration of rocks beneath overlying lava flows we do not find in our experience to be at all universal; nor yet, when it occurs, save perhaps in the case of highly argillaceous rocks (and here we should note the entire absence of induration in the clayey shale and shaly conglomerate seen respectively in contact with the trap on the north and south sides of the ravine), do we consider it as at all necessarily the result of the heat of the overlying lava, but rather as the result of the infiltration of calcareous or silicious solutions from the superior rock, such as might occur long subsequent to the cooling of the lava. If, then, a mass of rock fitted to supply the proper material to form indurating solutions be superposed in any way—whether by igneous outflow, sedimentation, or faulting movement—upon a rock capable of receiving induration by percolating solutions, then such induration is liable to occur quite independently of the modes or relative times of formation of the two rocks concerned. A calcitic induration we have frequently observed developed to a far greater degree than we have yet observed in the case of any of the Keweenawan sandstones in places on the contact between the silecious sandstones of the Potsdam and the limestones of the overlying Lower Magnesian, in Wisconsin. A calcitic induration, then, might well result along such a contact as we have on the Douglass Houghton River by the downward percolation of lime-bearing solutions. We may also repeat in the same connection the reference several times made already to the abundant occurrence in many sandstones of strong silicious indurations wholly apart from and manifestly independent of any igneous agency.

In the account above quoted as given by one of us in his volume on the Copper-Bearing Rocks of Lake Superior, he takes the position, as Rominger did independently afterwards, that the true Keweenawan beds extend for some 300 paces below the falls, beyond which, after passing a covered interval of some width, the horizontal sandstone beds next met with were regarded as belonging to the true Eastern Sandstone. In explanation of this position, which he finds himself now forced to abandon, he has to say that at the time of his own examination no question had been raised as to the correctness of Agassiz's and Pumpelly's views with regard to the existence here of a true unconformity. His object was chiefly to satisfy himself as to the occurrence of Keweenawan detritus in the true Eastern Sandstone. Having succeeded in this, no further detailed examinations were made at the time, although the northwesterly

TORCH LAKE QUARRY KEWEENAW POINT. FROM THE EAST.

[From a photograph. The vertical lines on the edges of the layers are drill holes.]

[illegible]

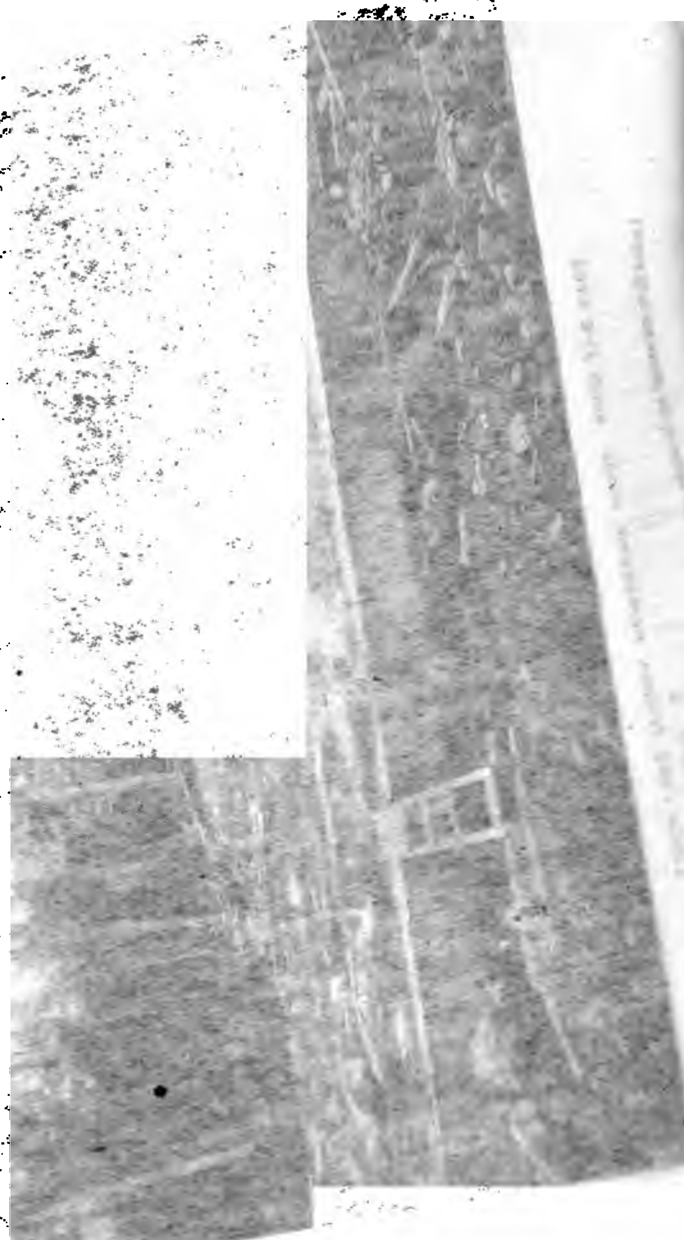
[illegible] was the [illegible] Series. [illegible] Wad[sworth] [illegible] appears as [illegible] of interpretation [illegible] were published, these [illegible] [illegible] to prove that [illegible] covered [illegible] a further examination [illegible] measurements of [illegible] revealed [illegible] will be seen from his notes [illegible] entirely with [illegible] Mr. Chauvenet was unable [illegible] out, so explicit were Mr. Wadsworth's [illegible] that he might not have looked [illegible] these things into consideration [illegible] was [illegible] Our further examination has served to show, [illegible] question, that the [illegible] Sandstone [illegible] contain 130 steps of the [illegible] the northwesterly [illegible] fore considered to be part of the Keweenaw [illegible] belong [illegible] to the Eastern Sandstone. [illegible] manuscript notes of Dr. C. Rominger [illegible] it will be seen [illegible] was disposed to give [illegible] westerly dipping beds, although [illegible] lithological similarity of these layers [illegible] Sandstone farther down the stream.

[illegible] QUARRY.

This quarry, whose position is shown on Figure [illegible] because of its close proximity to the junction of the Keweenaw Series and the Eastern Sandstone, here [illegible] a considerable altitude as it does — 340 feet above the level of [illegible] Lake, or only 28 feet lower than the top of the Douglass Houghton [illegible] it is manifest that if those are correct who would regard the [illegible] sandstone as inferior to the Keweenaw Series and as steadily decreasing in northwesterly dip for a mile or [illegible] southeast from this [illegible] considerable northwestern dip should be expected in the rock of the quarry.

The following are quotations from those who have examined this quarry, in the order of the time of examination:

M. E. Wadsworth, 1879. (Bull. [illegible] of Comparative Zoölogy, Vol. [illegible], No. [illegible], [illegible] 17, 18[illegible]) "In the [illegible] quarry [illegible] the [illegible] Railroad, the sandstone layers have been [illegible] as being nearly [illegible] planes that form the [illegible] of the quarry [illegible] to the northwest; but these [illegible] cannot [illegible] bedding planes [illegible] close examination [illegible] layers of coarser material, pebbles [illegible] in the rock. These layers [illegible] for long distances through [illegible]



dipping sandstone beds near to the traps were observed and the query was raised as to whether they were not probably part of the Keweenaw Series. Subsequently, when Mr. M. E. Wadsworth's very explicit statements as to the occurrence here of intercalations of trap and sandstone were published, these statements were accepted without question, and considered to prove that the query above referred to should be answered in the affirmative. Some time afterwards Mr. W. M. Chauvenet made a further examination of the ravine, and made some more detailed measurements of dip, with the results recorded above, which results, as will be seen from his notes, coincide closely with our own observations. Mr. Chauvenet was unable to find the intercalations of trap and sandstone, but, so explicit were Mr. Wadsworth's statements, it was supposed that he might not have looked for them in just the right place. Taking all these things into consideration a conclusion was reached as above given. Our further examination has served to show, however, beyond all question, that the true quartzose Eastern Sandstone extends to within 130 steps of the falls, and that the northwesterly dipping layers, before considered to be part of the Keweenaw Series, belong unmistakably to the Eastern Sandstone. In the quotation above given from the manuscript notes of Dr. C. Rominger, taken in 1883, it will be seen that he was disposed to give substantially the same explanation of the northwesterly dipping beds, although at the same time he recognized the lithological similarity of these layers to the true Eastern Sandstone farther down the stream.

TORCH LAKE QUARRY.

This quarry, whose position is shown on Figure 7, is of some little interest because of its close proximity to the junction of the Keweenaw Series and the Eastern Sandstone, here covered. Lying at such a considerable altitude as it does—340 feet above the level of Torch Lake, or only 28 feet lower than the top of the Douglass Houghton fall—it is manifest that if those are correct who would regard the Eastern Sandstone as inferior to the Keweenaw Series and as steadily decreasing in northwesterly dip for a mile or more southeast from this contact, then a considerable northwestern dip should be expected in the rock of this quarry.

The following are quotations from those who have examined this quarry, in the order of the time of examination:

M. E. Wadsworth, 1879. (Bulletin Museum of Comparative Zoölogy, Vol. VII, No. 1, pp. 117, 118.) "In the sandstone quarry at the head of the *incline* on the Hecla and Torch Lake Railroad, the sandstone layers have been regarded as being nearly horizontal. The joint planes that form the floors of the quarry are nearly so, having only a slight dip to the northwest; but these joint planes cannot be the bedding planes, for we find on close examination that numerous layers of coarser material, pebbles, clay masses, etc., occur in the rock. These layers extend for long distances through the sandstone,

and are always parallel, having the same dip, which is N. 45° W. 15°. These of course, from their character and regularity, must mark the old planes of bedding, while the generally supposed bedding planes are secondary joint planes cutting the bedding planes at a small angle. This sandstone * * * has been leached and acted upon by water the same as that below the Douglass Houghton Falls and its feldspathic material converted into clay or entirely removed. Part of the materials composing the sandstone, especially in the coarser portions, are similar to those in the sandstone

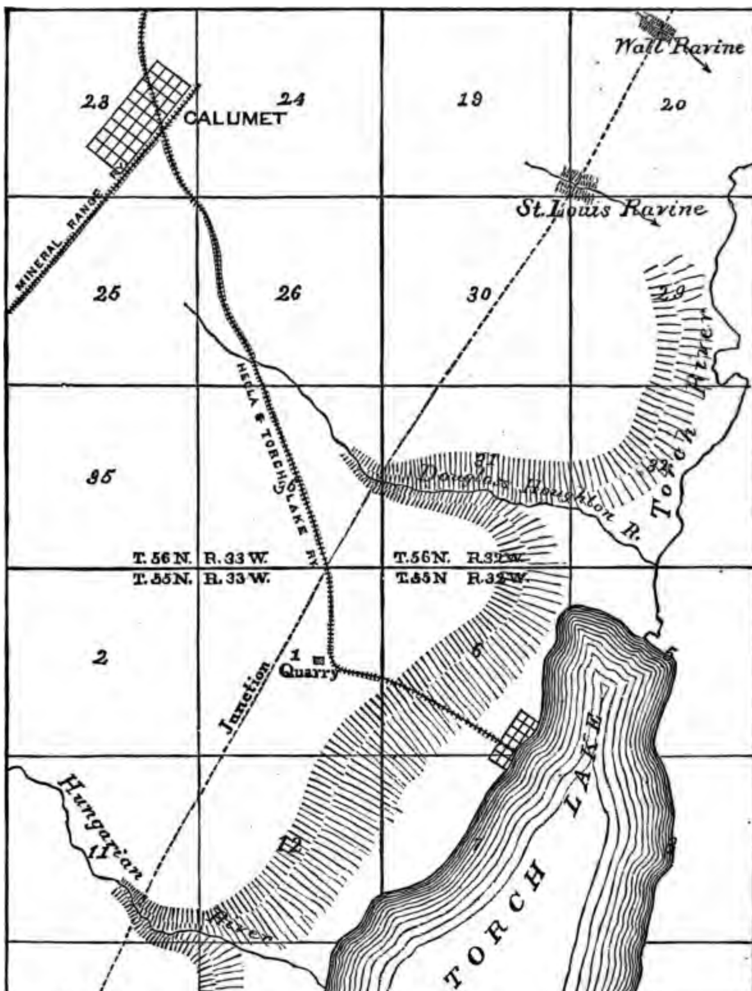


FIG. 7.—Plat of adjoining portions of T. 55, R. 32 W., T. 55, R. 33 W., T. 56, R. 32 W., and T. 56, R. 33 W., Keweenaw Point, Michigan.

at Marquette. The quartz grains are partly water-worn, but a large proportion are seen to be short crystals formed of the hexagonal prism, terminated on both ends by the pyramid, or the usual form found in the acidic porphyritic rocks. It appears, then, as the facets of these crystals are comparatively unworn, that they were derived from the destruction or decomposition of trachytic and rhyolitic rocks (granitic and *quartz porphyries), the feldspathic* [a misprint for felsitic] material having been re-

moved since by water, leaving a quartzose sandstone. It is a question worthy of examination whether any other sandstones have been formed from acidic volcanic material, from which nearly all the other parts of the rock have been removed by percolating waters, especially as other sandstones have been said to be composed of quartz crystals.

"As the sedimentary rocks are more and more studied, the evidence comes on every side that, like this sandstone, while their formation may have taken as long as is generally supposed, they may have been deposited very rapidly, some being composed of old volcanic scoria, ashes, and mud. In very many other cases the supposed sedimentary rocks are really volcanic flows or intrusive masses. In the sandstone just described the same masses of clay * * * occur as on the Douglass Houghton River, and they may arise here, as there, from the decomposition of the inclosed feldspathic or argillite pebbles. Another solution of the question of the origin of some of these would be the filling in of cavities formed by the removal of some other material, by the argillaceous material brought from above. This is suggested by the finding of stalactites of the sandstone * * * extending down into the clay. At the spring just above the quarry the sandstone * * * is red spotted with white, and dips N. 45° W. 14°."

R. D. Irving, 1880. (Copper-Bearing Rocks of Lake Superior. Monographs United States Geological Survey, Vol. V, pp. 356–359.) "About a mile south from the head of the Douglass Houghton ravine, on the line of the Torch Lake Railroad, is a large quarry in the Eastern Sandstone. The sandstone is disposed horizontally in heavy massive layers. It is nearly white and almost wholly composed of rolled quartz grains. It also contains here and there grains of feldspar, somewhat altered, but on the whole singularly fresh for such a rock, some particles showing the twin lamellation very beautifully. A very minute quantity of a brownish cement is present, and in each thin section may be seen two or three grains worn from some of the fine-grained diabases of the Keweenaw Series. Not a trace is to be seen of anything like the fragments of porphyry matrix, so abundant in the Keweenawan sandstones; nor was I able to discover any satisfactory indications that the quartz grains are the quartzes of the quartziferous porphyries, although one might expect to do so. In his description of this quarry quoted below, Mr. Wadsworth speaks of the grains of the sandstone as furnished with crystalline outlines, and regards these outlines as showing the derivation of the quartzes from a quartz porphyry. My sections fail to show any such outlines, but if they occur they are probably rather in the nature of those of the crystal grains so frequently met with in the Potsdam Sandstone of the Mississippi Valley, in which case the crystalline outlines are the result of a secondary deposition of quartz upon the surfaces of the originally rolled grains. Rare pebbles of quartz of some size are contained in this sandstone, and patches and lines of red clayey substance, which do not show any persistent inclination in any one direction. The clayey material often expands into large bunches of red clay forming the usual clay-holes so characteristic everywhere of the Eastern and Western horizontal sandstones.

* * * * * * *

"In my examination I failed to find any evidence of the northwesterly dip described by Wadsworth, and a subsequent examination by Mr. W. M. Chauvenet, with Wadsworth's description in hand, was equally futile. The reddish bands, as stated above, showed, so far as I observed, no one direction of inclination any more decided than the others; and even if they did, it would be necessary for any one trying to establish their direction as that of the general bedding of the rock, to prove that they should not rather be taken as instances of the cross-bedding so commonly affecting the similar sandstone of the Mississippi Valley, while both they and the larger clay bunches are precisely what may be seen in the plainly horizontal sandstones of the Apostle Islands. It would seem that Mr. Wadsworth, having previously formed a theory as to the relation of the Eastern Sandstone to the Keweenawan beds, has felt it necessary to explain away the plain horizontality of the rock in this quarry.

"A similar process has led him to the view that the feldspathic ingredient has been leached out of the Eastern Sandstone, in order that he may explain the quartzose character of this sandstone and of that of the Douglass Houghton and Hungarian rivers — a character which is in fact a common one of the Eastern Sandstone, wherever met with on the line between Bête Grise Bay and Lake Agogebic, and again along the north face of the South Range, east of Lake Agogebic. This leaching process would have but a slender theoretical basis at the best, and in the present case seems to be distinctly disproved by the appearance of the thin section, nearly the whole of which is formed of rounded quartz grains without any space for the feldspathic material to have been leached from; while the few feldspar grains present are singularly fresh for the grains of a fragmental rock. Moreover, the qaurtz particles cannot represent a secondary substitute for feldspar, such as so often occurs in the granitic porphyries of the Keweenaw Series. I cannot conceive of a leaching process which leaves neither space nor substitute for the original material. Possibly it is meant that the leaching has affected the rock as a mass and that the remaining material has collapsed. But this could not happen so as to leave the rock so distinctly marked by the original bedding structure. The thin section shows, moreover, the quartz grains frequently in the often observed relation which indicates that they lie where rolled together by shifting waters; *i. e.*, one grain enters a depression in the side of another. Again, it is difficult to see why the supposed hot waters should have selected this one sandstone for leaching, removed as it is, now at least, from the heating lava-flows, while the beds directly intercalated with these flows should in no instance show any signs of such a leaching. Although Mr. Wadsworth seems to have felt it necessary thus to explain away the peculiarly quartzose character of the Eastern Sandstone as compared with the sandstones of the Keweenawan, this lithological dissimilarity seems to me really rather more in favor of his peculiar view as to the structural relations of the Eastern Sandstone than against it."

W. M. Chauvenet, 1880. (Manuscript notes.) "In the sandstone quarry near Torch Lake, the main joints of the quarry, which are the surfaces of the layers, dip as the sandstone rolls, as much in every direction as in any one. Red streaks were occasionally noted running across the layers in a northwesterly direction, but as often rising again so as to present a southeasterly dip. This was seen very plainly marked on a face exposed to the east."

M. E. Wadsworth. (Bulletin Museum of Comparative Zoölogy, Vol. VII, No. 11, p. 564, 1884.) "Irving further denies the general correctness of Wadsworth's previously published statement relating to the sandstone quarry near Torch Lake (*ante*, pp. 117, 118), and maintains that, while he (Irving) finds traces of the trappean material in the sandstone, he does not find any of the porphyry material belonging to the conglomerates of the 'Keweenawan Series.' This claim proves too much; for if this sandstone had been deposited against the mixed lava-flows and detrital rocks of the copper-bearing series, as Irving holds, and made up of their ruins, there the sandstone should be full of their débris and the old rhyolitic and trachytic material ought to be far longer retained than the more easily perishable basaltic material, since even in the sandstones intercalated with the traps the basaltic débris is comparatively rare. Now Irving's statements are directly opposed to his own views; and the same may be said of the testimony of all those who claim that the sandstone near the traps is composed of different materials from those of the detrital rocks of the so-called Keweenawan Series.

"Wadsworth has since re-examined the specimens in the collection made with express reference to retaining the evidence in behalf of his previous statements (*ante*, pp. 117, 118), and he reiterates those statements with the exception of this correction, that on page 117, third line from the bottom, the word *felsitic* is misprinted *feldspathic*, as the context shows. He finds in these specimens an abundance of the bi-pyramidal quartz peculiar to ancient and modern rhyolitic rocks, and also the variation between the bedding planes and jointing, both being evident in the hand specimens."

R. D. Irving and C. R. Van Hise. (Bulletin of the United States Geological Survey,

No. 8, 1884, pp. 40, 41.) "Quarry on Torch Lake Railroad, Keweenaw Point, Michigan. A white to pinkish, feebly indurated quartzose sandstone. Some of the less indurated portions show numbers of faceted grains. The slide here described is from one of these less indurated portions. It is seen to be made up almost entirely of much rolled quartz fragments, which have in nearly every instance been enlarged, the enlargements only occasionally showing crystalline outlines. These crystal outlines are, however, more frequently to be seen in the balsam mounting of crumbled sand. They are not nearly so numerous, however, as in some of the rocks previously described, the grains having interfered too much to form crystal outlines. The outlines of the original grains are usually very strongly marked by brownish iron oxide. There are occasional rounded fragments of feldspar present, and in each thin section may be seen a few particles worn from some of the fine-grained Keweenawan eruptives. * * *

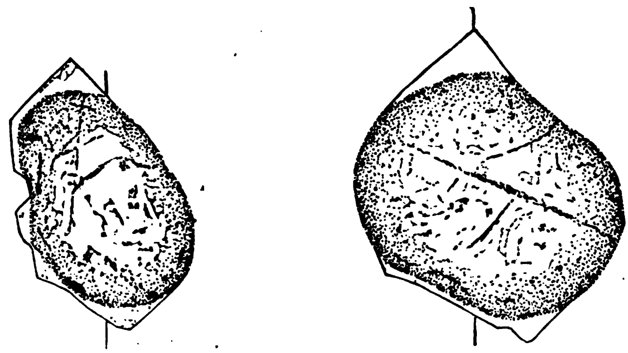


FIG. 8.—Crystal-faced enlargements of quartz fragments from sandstone of Torch Lake Quarry, Keweenaw Point. Scale 67 diameters.

"See, with regard to this rock, also Copper-bearing Rocks of Lake Superior; pp. 356–358. See, also, for an earlier description, M. E. Wadsworth in Bulletin Museum of Comparative Zoölogy, Vol. VII, No. 1, p. 117. Wadsworth found the crystal-outlined grains abundantly in his sections, although we failed to do so in ours until recently. He regarded these crystal grains as being the usual dihexahedral crystals of quartz-porphyries, on which view the crystals antedate the formation of the sandstone instead of being subsequent to it. More recently (Science, Vol. II, No. 23, p. 52, July 13, 1883) he has reasserted this view. But a careful re-examination of this rock, as also of others from other places within the area of the Lake Superior sandstone, has served to convince us that in all of these cases, as in all sandstones yet examined by us provided with such faceted grains, they owe their crystal faces to secondary enlargements of rolled fragments. It is of course possible and even probable that these quartz fragments were once, some of them, the quartzes of quartz porphyries, but if so they have rarely, if ever, retained their crystal faces, as it is, indeed, hardly conceivable that they should do."

To the descriptions of this quarry, already published by one of us as above quoted, we have little to add, and from them nothing to take away. We re-examined the quarry-face carefully together and took the photograph here reproduced. We have no hesitation whatever in saying that the rock is here, as it appears to be, in an essentially horizontal position. There are some indications of bowing, and at the northwestern end of the quarry there are indications of a northwesterly dip, a natural enough occurrence when we consider how near to a junction

with the traps we here are, and that the sandstone must be affected here by the same disturbances as seen on the Douglass Houghton River. We examined some of the lines of pebbles, or rather of sandstone, slightly coarser than the rest, referred to by Mr. Wadsworth. These lines, however, certainly do not have any persistent single direction. We were even able to follow single lines through a change from a northwesterly to a southeasterly inclination. Moreover, these lines are most plainly lines of false or cross bedding, and not very pronounced ones at that. Any one who has had much experience among sandstone formations has seen far more strongly marked instances of false bedding and cases more liable to deceive by leading one to regard them as the true lines of bedding; as, for instance, everywhere throughout the Potsdam Sandstone of Central Wisconsin. In the Eastern Sandstone itself false bedding may be seen at several points much more strongly pronounced than here; for instance, on the south side of the mouth of Hungarian Ravine. Furthermore, the bedding planes are perfectly distinct, and present those characters that distinguish bedding planes from joint planes. They are not ripple-marked in the technical sense, but they present those undulatory wave-fashioned surfaces which to the experienced observer are equally decisive of their origin.

HUNGARIAN RAVINE.

The Hungarian River is, after Torch River, the principal tributary of Torch Lake. Heading in the southern part of T. 56, R. 33, in the vicinity of the Osceola mine, it runs in a general southeasterly direction to Torch Lake, which it enters in the northern part of Sec. 13, T. 55, R. 33 W. In the southeast quarter of Sec. 11 it crosses the junction of the Eastern Sandstone and the Keweenaw Series, below which junction it runs through a continually deepening ravine with several heavy falls, until it reaches the narrow strip of lowland bordering Torch Lake. As we learned from Mr. P. C. F. West, chief engineer of the Calumet and Hecla mine, who has kindly furnished us a copy of a carefully leveled profile of the Hungarian River, the entire descent of the river from the top of the uppermost fall to Torch Lake is 361 feet. In this distance the river makes three main falls, besides two smaller ones, all of them over the Eastern Sandstone, except the two uppermost ones. Of these last the upper one is a leap of 25 feet over Keweenawan conglomerate, the lower, only a short distance below, one of 8 feet, over diabase and amygdaloid. The fall nearest to Torch Lake is the main one, having a height, according to Mr. West's measurements, of 144.3 feet. The general position of this ravine is indicated on Figure 7.

So far as we have learned, the only geological examinations of this ravine made before our own have been those by Messrs. M. E. Wadsworth, W. M. Chauvenet and Dr. C. Rominger. The following quotations give the results obtained by these several observers:

M. E. Wadsworth, 1879. (Bulletin Museum of Comparative Zoölogy, Vol. VII, No. I, July, 1880, pp. 113–115.) "As we followed the Hungarian River, a tributary of Torch Lake, upward, starting from the low sandy plains near the lake, the sandstone was first observed forming high bluffs on both sides of the river and dipping N. 45° W. 10°. It occurs in coarse and fine layers often inclosing pebbles. As the river is ascended the layers of pebbles were seen to curve in various directions with an irregular dip, but which in general inclined to the northwest. Some of the pebbles appeared to be of quartzite similar to that at Carp River, Marquette. * * * The Hungarian Falls are formed by the river being precipitated over several ledges of the sandstone and conglomerate. Several specimens were taken, showing the different varieties of pebbles composing the conglomerate. * * * No. 523 is an old trachyte composed of a reddish-brown groundmass, holding white kaolinized feldspars, dark-brown decomposed hornblende crystals, and a little mica. It is closely allied to some of the modern rocks from the Cordilleras. The groundmass is now kaolinized, forming a dirty-white mass holding secondary quartz and feldspar, as well as long narrow ferrite masses. These latter appear to have been formed from the hornblende fibres, so frequently seen in the allied rocks from the Cordilleras. The groundmass has now through its alteration a spherulitic structure. No. 524 is a more compact rock of like character. Its groundmass is kaolinized and holds the quartz and feldspar alteration products. It is filled with grains and masses of ferrite probably derived from hornblende. The feldspar is so decomposed that it cannot be told whether it is plagioclase or orthoclase. * * *

"No. 527 has a more coarsely crystalline, granitoid structure, showing under the lens a reddish and grayish-brown groundmass, holding elongated brownish-black hornblende crystals. In the thin section it is seen to be composed of feldspar, magnetic iron, hornblende, and some quartz. The feldspar is greatly altered, and is now composed of intergrowths of feldspar and quartz, giving rise in it to a structure resembling that of graphic granite, or much of that figured as belonging to the Eozoön Canadense. The quartz is all secondary, and the hornblende altered to reddish or yellowish-brown ferruginous masses.

"No. 528 is a fine-grained granitoid trachyte (granite porphyry), but in the thin section the feldspar is seen to be so altered and filled in with secondary quartz, containing full and bubble-bearing fluid and vapor cavities that the section resembles that obtained from some fragmental rocks.

* * * * * * *

"Below and at the base of the falls the dip remains the same as before, N. 45° W. 10°, but above this locality the inclination varies, rising from 15° to 18° between the first and second falls. In some places a quaquaversal dip was seen. Some five falls exist in the river, and at the last or upper fall the melaphyr was found. The dip of the sandstone has now increased to some 20° but still dips northwest, and the first trappean flow is seen to overlie and greatly indurate and alter it. This immediately underlying sandstone * * * is filled in with little reticulated veins of calcite, a kaolin-like material, etc., and in general resembles the baked sandstone found underlying the trap on the western side of Keweenaw Point. Microscopically, it is seen to be composed of the *débris* of the trachytes previously described. This sandstone was seen within 3 inches of the melaphyr, and although there may have been some sliding motion between the two, as the contact was not seen, yet the induration of the sandstone, its dip, and its relations to the melaphyr, prove that it underlies the latter, which flowed over it. This, then, with evidence obtained on the Douglass Houghton River, settles the long disputed question of the relative age of the traps and eastern sandstones of Lake Superior. The dip of the melaphyr is about the same as that of the sandstone. Immediately above this thin lava sheet, a conglomerate comes in, forming the fifth fall. The base of this conglomerate is composed of a fine-grained detritus formed from the melaphyr and trachyte, and holds numerous pebbles of the melaphyr, as well as of the other rocks. * * * Immediately overlying this conglomer-

ate is another melaphyr flow, and we have here on the eastern side a repetition of the same alternate bands of melaphyr and sandstone that occur on the western side."

W. M. Chauvenet, 1880. (Account prepared from Mr. Chauvenet's notes by R. D. Irving, Copper-Bearing Rocks of Lake Superior. Monographs United States Geological Survey, Vol. V, 1883, pp. 354, 355.) "As the Hungarian River is ascended, the sandstone is first met with on the sides of the ravine, and then in its bed also, where it forms several falls. For the most part the sandstone is light-colored and quartzose, but conglomerate bands are included in which the pebbles are in the main of some of the red acid eruptives of the Keweenawan. Often the sandstone lies horizontally; at times it appears to have a slight northwesterly dip, and as often a slight southeasterly one. These deviations from horizontality are often plainly the result of the undermining on the side of the ravine. At the uppermost fall the contact with the older rocks is seen. The occurrences here, and for some distance below, are as shown in the accompanying sketch, made on the ground by Mr. W. M. Chauvenet, in which B is the bank of the gorge without exposures; A, sandstone layers projecting from the sides of the bank; D, amygdaloid and pseud-amygdaloid dipping northwesterly; E, the continuation of the amygdaloid in a crumbling condition; C, porphyry conglomerate; and F, an overlying diabase. At G, at the very foot of the fall, is a smoothed surface of sandstone jointed in two directions, the two joint surfaces dipping NW. 25° and S. 20° E.; and a few steps farther down the sandstone is seen lying perfectly flat. In the same vicinity true bedding, as shown by the differences in the coarseness and coloring of the sandstone, gave dips of NW. 10°, SE. 20°, NE. 20°. The irregularities seem to be due, in a measure, to undermining on the sides of the ravine, but are also apparently somewhat analogous to those described and figured on a previous page as occurring on the gorge of Black River, in Douglas County, Wisconsin—*i. e.*, are the product of faulting motion.

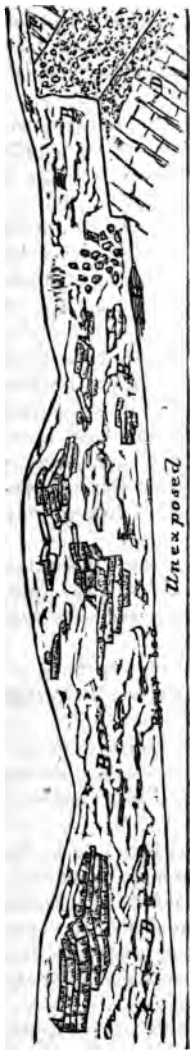


FIG. 9.—Section on the Hungarian River, Keweenaw Point.

"In his account of the occurrences on the Hungarian River, Mr. M. E. Wadsworth has represented the Eastern Sandstone as presenting a gradually increasing northwesterly dip, as it is followed up the stream, until it is plainly seen plunging beneath the Keweenawan diabase and interbedded conglomerate. But neither the increasing northwesterly dip nor the subordinate position of the sandstone to the diabase could be detected by Mr. Chauvenet. Northwesterly dips are found in the sandstone for some distance below the contact, but southeasterly ones just as often or oftener, and both seem distinctly subordinate to a general horizontality. Again, sandstone lies vertically beneath an amygdaloid, but the mass of sandstone appears to be a fallen one, and if it is not, the crumbling amygdaloid above certainly is."

The following are verbatim quotations from Mr. Chauvenet's manuscript notes taken on the ground:

"The sandstone in the stream-bed a short distance below the lower leap seems to lie perfectly flat, and at a point 75 feet below this fall horizontal layers of sandstone rise 30 feet in the south bank.

"There is an exposure of smoother sandstone in the stream-bed below the second jump of the fall. This shows white streaks in a dark reddish-brown mass and joints running in two main directions. The dips measured on these joint surfaces were NW. 20° to 25° and SE. 20°. But immediately below the sandstone is nearly horizontal. Although dips were found on true bedding planes 10° NW. yet at the same place dips 10° and 20° SE. and NE. were obtained. The mass of rock is, in short, fallen and caved and much undermined.

"The amygdaloid is seen on the right bank and in the stream 6 feet from the sand rock. It seems to hang above it on the right, rising 20 feet above the stream in a loose broken mass, but nothing was seen here in place. Just above [up-stream from] the trap comes in with a thickness of 20 feet or more, forming the second leap of the falls and continues to the base of the upper falls, where it passes underneath the overlying conglomerate.

"Following the stream downward from the junction the sandstone is seen rising into bold exposures which show much disturbed jointing. Layers evidently parallel to the true bedding are seen to lie horizontally, although at times seen dipping in many directions."

C. Rominger, 1883. (Manuscript notes taken in the summer of 1883.) "Ascending the ravine of Hungarian Creek, with steep, almost inaccessible sides, I found, below, the sole of the creek formed of horizontal sand-rock beds, and came, in progress of the ascent, to the base of the perpendicular rock-walls, approximately not far from 100 feet in height, over which the creek falls down in a cascade. These rock-walls consist of a succession of reddish-colored horizontal layers of sandstone, similar to the lower beds seen in the creek-bed below. Above the falls the horizontal sandstones continuing to be exposed in the creek bed and on the sides, I came to several other falls from 20 to 25 feet in height, which all were caused by offsets in the great succession of horizontal sandstone beds. Finally, close to the summit of the ridge, I saw another fall about 20 or 25 feet high, which was caused by the projection of a conglomerate belt and of an amygdaloid belt beneath it, both of which layers dipped under an angle of about 45° to the northwest.

"The amygdaloid belt is about 30 feet thick, and is seen to come into immediate contact with horizontal layers of sandstone in the bed of the creek. Sideways from the creek channel the contact cannot be seen, as the surface is covered with loose material.

"A dip of the sandstone under the amygdaloid, as Mr. Wadsworth asserts, is not observable; on the contrary, a slight southern dip of the sandstone strata away from the amygdaloid is noticeable.

"The quartzose, rather light-colored quality of the sandstone forming the contact, is unlike the sand rocks ordinarily found in connection with the copper-bearing rocks, but it exactly corresponds with the usual appearance of the Eastern Sandstone exposed along the shore of Keweenaw Peninsula."

M. E. Wadsworth, 1879. (Bulletin Museum of Comparative Zoölogy, Vol. VII, No. XI, August, 18-4, pp. 563, 564.) "Irving further claimed that at the junction of the sandstone and traps on the Hungarian River * * * the sandstone was a loose piece, or, if not, the basaltic rock surely was, and that the prevailing dip of the sandstone was to the southeast.[1] To this Wadsworth replied, "that the dips given in the report (Irving's) appeared to have been taken from the frost-dislocated rock on the sides of the

[1] No such statement was ever made. A reference to the quotation a few pages back will show that my words were, "Northwesterly dips are found in the sandstone for some distance below the contact, but southeasterly ones just as often or oftener, and *both seem distinctly subordinate to a general horizontality*," which is very far from saying that the prevailing dip of the sandstone is to the southeast. (Third Annual Report of the Director United States Geological Survey, p. 150, and Monographs United States Geological Survey, Vol. V, p. 355.)—R. D. I.

stream, while his (Wadsworth's) were taken in the bed of the stream, when the water was exceptionally low.[1] He further stated that the sandstone at the junction was continuous with that seen below; that it extended across the stream and into the banks on both sides; while the baking and induration of it showed that it must have been overflowed by some heated rock. Again: the basaltic rock extended across the stream into both banks and was found to underlie the conglomerate, and that he dug the *debris* of the former out of the overlying base of the latter. All this, he said, showed conclusively that these rocks were *in situ*, and proved that here the eastern sandstone and Keweenawan series were one and the same; also, that this series could not be maintained, as first established."

Following up the ravine of the Hungarian River from Torch Lake, the first rock we encountered is a white to brown quartzose sandstone, in thick beds, dipping up stream, or northwest, at an angle of from 7° to 10°. This is on the south side of the mouth of the ravine. Interstratified with these heavier layers, which at times reach eight and ten feet in thickness, are thinner ones, six inches to two feet in thickness, of red and white banded sand, in which false or current bedding is very beautifully shown. At least 50 feet in thickness of these layers are visible here. There may have been some slipping on the bank, but we think it is evident that these layers occupy essentially their true position. Pebbles are almost entirely wanting, but here and there a small one may be found. So far as we observed these occasional pebbles, they are from some of the acid eruptives of the Keweenaw Series. Immediately opposite to this exposure on the north side of the ravine similar layers are exposed.

As the ravine is ascended still further the sandstone appears at so frequent intervals in both banks as to constitute what amounts to an almost continuous exposure, the sides of the ravine at the same time rapidly increasing in height and the exposures in vertical extent. The dips are all low, ranging from 10° as the highest down to horizontality. On the whole, northwesterly inclinations are perhaps the most common, but southeasterly and southwesterly ones also occur. As the formation is traced up the stream, the pebbles gradually increase in quantity. The distribution of these pebbles is, however, somewhat inconstant, in both vertical and horizontal directions, *i. e.*, they appear in certain layers rather than in others, and in these irregularly. Still, there is a very notable general increase in quantity as the stream is ascended or as the exposures of Keweenawan rocks are approached. In one instance, on the north side of the ravine, some 200 to 300 steps above

[1] As to this, it is to be said (1) that, after making all allowances for dislocation on the sides of the ravine, there remains an unquestionable bowed condition to the sandstone; (2) that this bowed condition was noticed in the bed of the stream as well; (3) that Mr. Wadsworth's own observations must have in large measure depended for that portion of the ravine below the immediate junction on the exposures in the walls of the ravine, there being frequently no exposures in the bed of the stream for long distances; and (4) that while Mr. Wadsworth maintains that on the Hungarian the place to look for dips is the bed of the stream on the Douglass Houghton one must *depend on* the "slippery sides of the ravine."

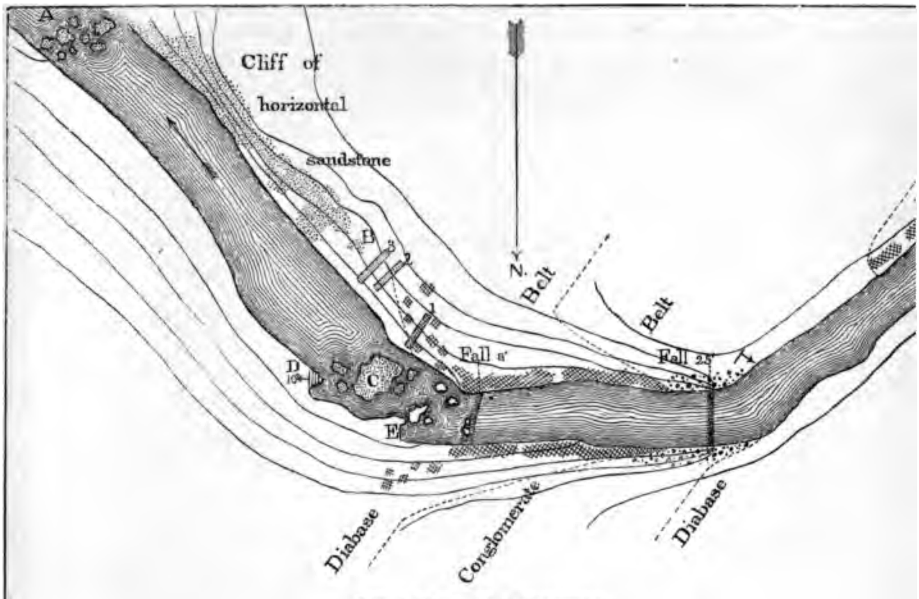


Fig. 1.-Plat of Exposures.

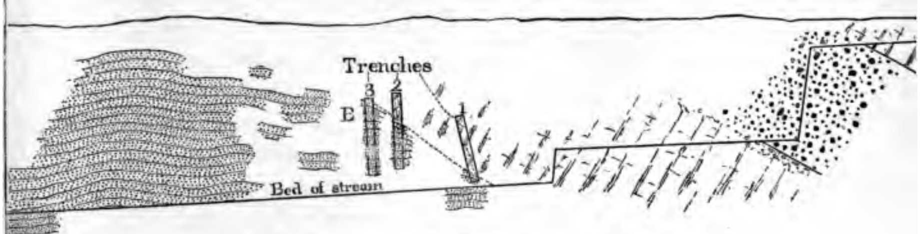


Fig. 2. Elevation of south bank showing Exposures.

Fig. 3. Ideal section showing structure.

JUNCTION OF THE EASTERN SANDSTONE AND THE KEWEENAW SERIES, HUNGARIAN RI

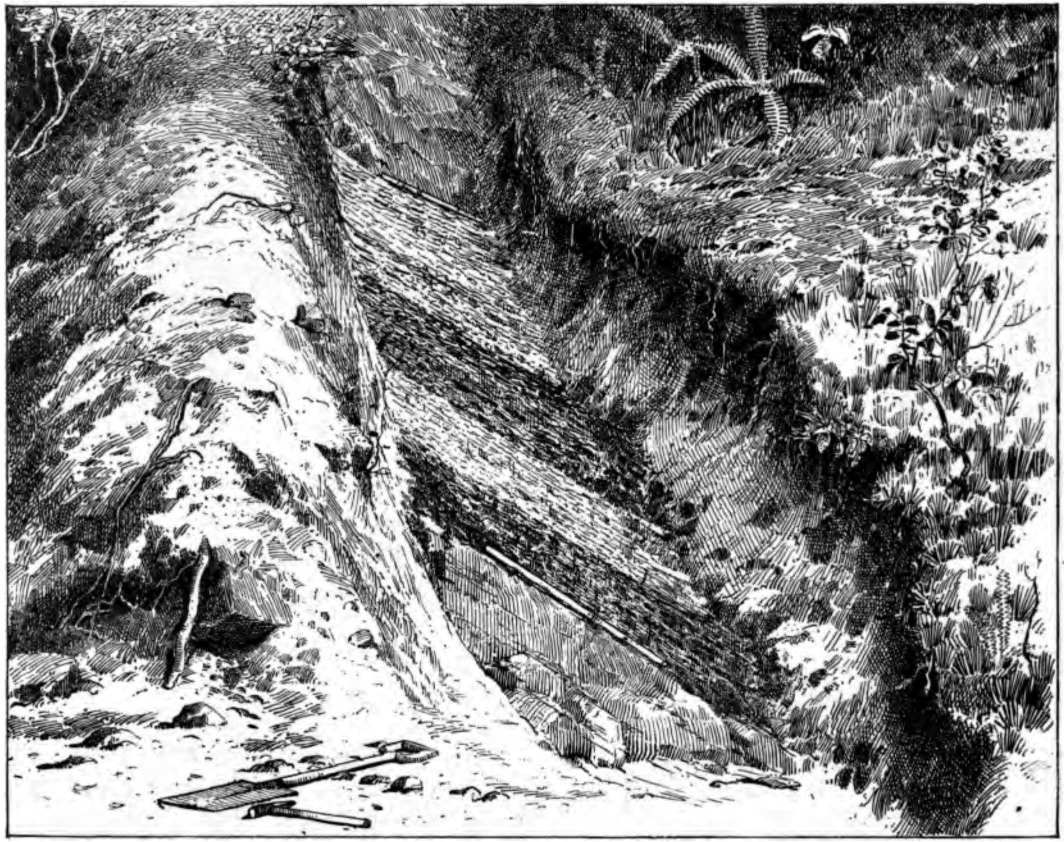
Scale: 1 inch = 50 feet

the first exposure mentioned, a conglomerate horizon is seen to come in, along which, as one passes westward, the pebbles increase gradually, but very notably, in number, closeness of setting, and vertical depth of distribution. What is at first a mere line of pebbles increases until it becomes a belt ten feet or more in width. Two important peculiarities of these conglomerates are to be noted. In the first place the pebbles are *scattered through the sandy matrix*, and are generally separated from each other by intervals varying from several inches across downwards. In other words, the assortment and classification of the constituents are not nearly as complete as is common among conglomerates, for instance, the ordinary Keweenawan conglomerates. Had the agencies completed their work, the pebbles would have been gathered into strata with which only so much sand would have been associated as could have found protection from the strong pebble-moving currents by lodging in the interspaces between the pebbles or in the lee of little banks or hillocks of pebbles. While this ideally perfect assortment is often not completely reached, there is in this instance an unusual shortcoming, an unusual dispersion of the pebbles through the sand, which certainly suggests quite pointedly that the process of assortment was not here carried to its usual extent; which conclusion, in its turn, suggests as certainly that the material was not of distant derivation. The other peculiarity referred to is the very striking manner in which the pebbles and bowlders protrude from the rock face. At times this projection is as great as two-thirds of the body of the pebble, which thus retains its position by means of cementation and not by interbedding. This peculiarity is but another expression of the characteristic above noted. The sandstone matrix weathers back with approximate uniformity, leaving the dispersed pebbles projecting as warty protuberances and thus giving a knotty face that we have never before seen in an equally pronounced development.

As the ravine is now ascended farther toward the main falls the sandstone series increases in height of vertical section and embraces sandstones, shales and conglomerates. The included sandstones remain predominatingly quartzose, and of whitish, yellowish or pale reddish casts, but never of dark hues. The shales are of the soft clayey varieties, and usually are of dull but rather dark reddish colors. The pebbles of the conglomerates, so far as those examined by us are concerned, are wholly of Keweenawan derivation. This conclusion we base not only upon the macroscopic notes taken upon the ground, but also upon careful microscopic study of thin sections. On the whole, the pebbles from the acid eruptives of the Keweenaw Series are the most abundant, but pebbles unmistakably from the basic members of that series are also abundant. At the main falls a section of upwards of 100 feet is finely exposed, in which may be well seen the alternations of sandstone, shale, and conglomerate. The position of the layers here is but little, if at all, removed from horizontality.

Above the falls the same general conditions continue, but as the stream is ascended the conglomeratic and red shaly layers lessen, and some little time before reaching the junction are entirely lost, and the only rock seen along this part of the course of the river is white yellowish or reddish very highly quartzose sandstone. This change is manifestly due to an ascent in geological horizon, the uppermost sandstone seen in this part of the ravine lying about 120 feet vertically above the top of the main falls. In this distance the layers seen in the bed and on the sides of the stream present many different inclinations, at times lying horizontally. Some of these variations in inclination are doubtless, as Mr. Chauvenet suggests, the result of undermining on the sides of the stream, but we think there can be no question whatever that they represent on the whole the actual condition of the sandstone; that is to say, they show that its layers lie in a disturbed or bowed condition. We were certainly unable to detect anything like a steady increase in northwestern dip. It is of particular interest to note in this connection that some of the longest stretches through which the layers are essentially horizontal are met with between the junction and a point 200 to 300 steps below.

The positions and relations of the exposures at the junction with the Keweenawan traps are indicated on the map and sections of Plate XIV. Here we found the general situation to be much as described by Mr. Chauvenet and pictured in the section above copied from him. Beginning at the right hand or eastern end, Figures 1 and 2 of Plate XIV—the former of which figures is a plat of the exposures, and the latter a profile section of the south bank of the stream—are designed to show nothing more than may be actually seen here. We note first a quite prominent and bold exposure of the Eastern Sandstone on the south bank of the river. The sandstone here rises in the bank to a height of between 30 and 40 feet, forming in places an overhanging cliff. The rock is a quite purely silicious sandstone, and is in general disposed distinctly in horizontal layers, but subordinate to this horizontality are sudden and abrupt transitions in different directions, the whole presenting the appearance of horizontal layers that have been subjected to a crushing force moving from the west. While a few of the deviations from horizontality may be due to undermining on the banks of the stream it is manifest that for the most part they are not so, since they occur, not merely on the cliffy exposures, but also in the exposures in the bed of the stream, as is seen for instance at the point A on Figure 1 of Plate XIV. At this point, on good-sized exposures extending across the bed of the stream, dips may be obtained plainly parallel to the bedding of the rock, of 5° to 10° in directions both up and down the stream, *i. e.*, both northwest and southeast. In the thin section the sandstone of this cliff shows the ordinary characters of the Eastern Sandstone. The section is made up predominatingly of quartz fragments, *with which* are mingled others of feldspars and unmistakable pieces of



[illegible] the basal and [illegible] we are also [illegible] sections a siliceous induration of the [illegible] in other more friable kinds this [illegible] cementing material is a mingling of [illegible] none of this sandstone were any [illegible] seen. [illegible] quite above the pebble-bearing horizon. A [illegible] cliff, drawn from a photograph, is given [illegible]

As the sandstone cliff is followed [illegible] with the trap it becomes more [illegible] exposures of the sandstone present [illegible] seen on close examination to retain [illegible]

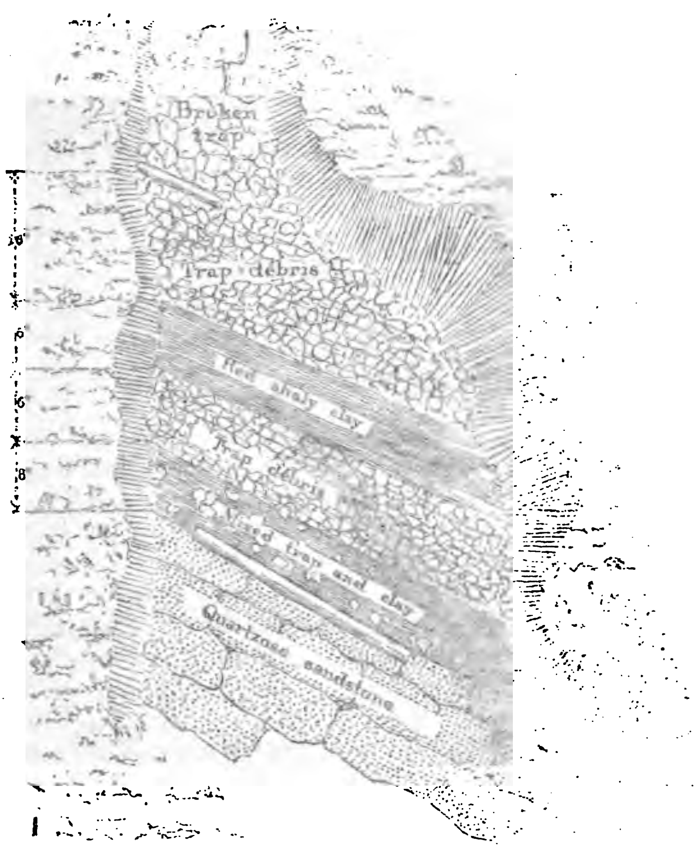
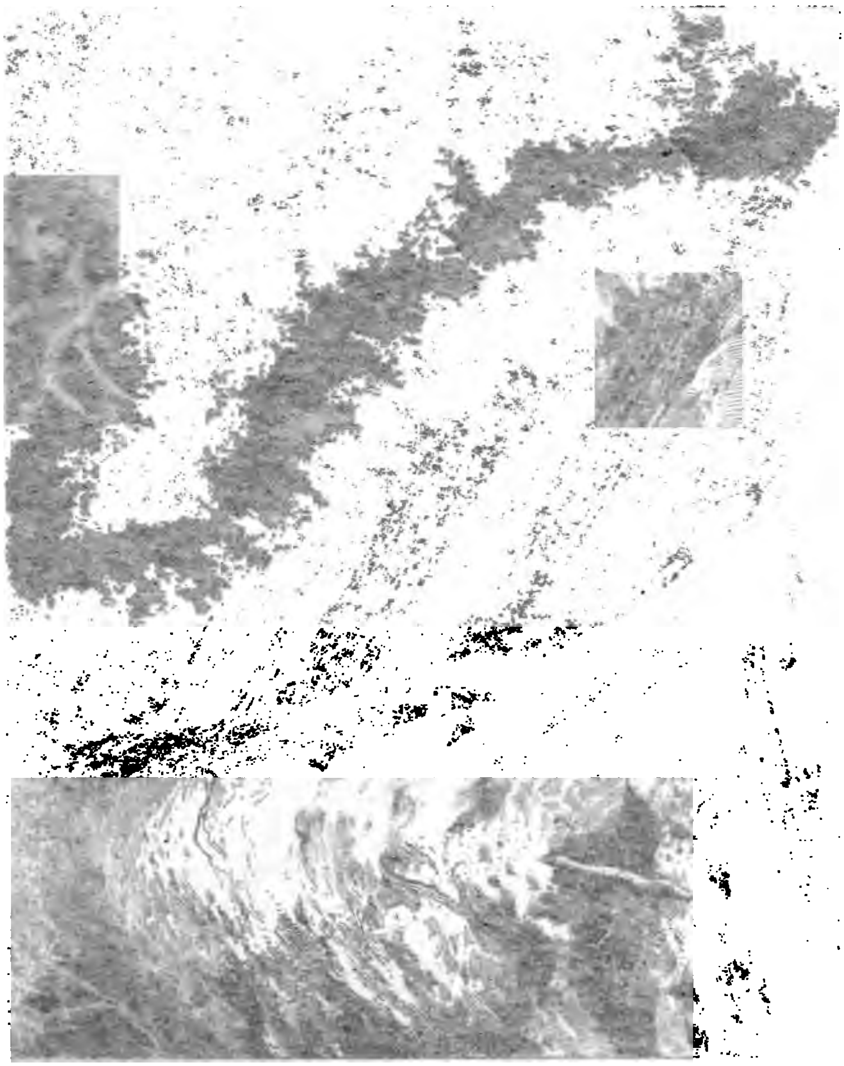


FIG. 10.—Section exposed in trench on Hungarian [illegible]

[illegible]tion. The last one of these exposures (B of Fig. [illegible]) a distance, measured horizontally along the [illegible] naturally exposed crumbling mass of trap. [illegible]



the fine matrices of the basic and acid eruptives of the Keweenaw Series, to which source we are also inclined to refer the feldspar fragments. In some sections a silicious induration of the usual kind is seen to affect the rock. In other more friable kinds this is absent, and the only cementing material is a mingling of oxide of iron and clayey matter. In none of this sandstone were any pebbles seen. We appear here to be quite above the pebble-bearing horizon. A view of this sandstone cliff, drawn from a photograph, is given in Plate XVII.

As the sandstone cliff is followed up-stream toward the junction with the trap it becomes more interrupted, and finally only detached exposures of the sandstone present themselves. These, however, are seen on close examination to retain still the essentially horizontal posi-

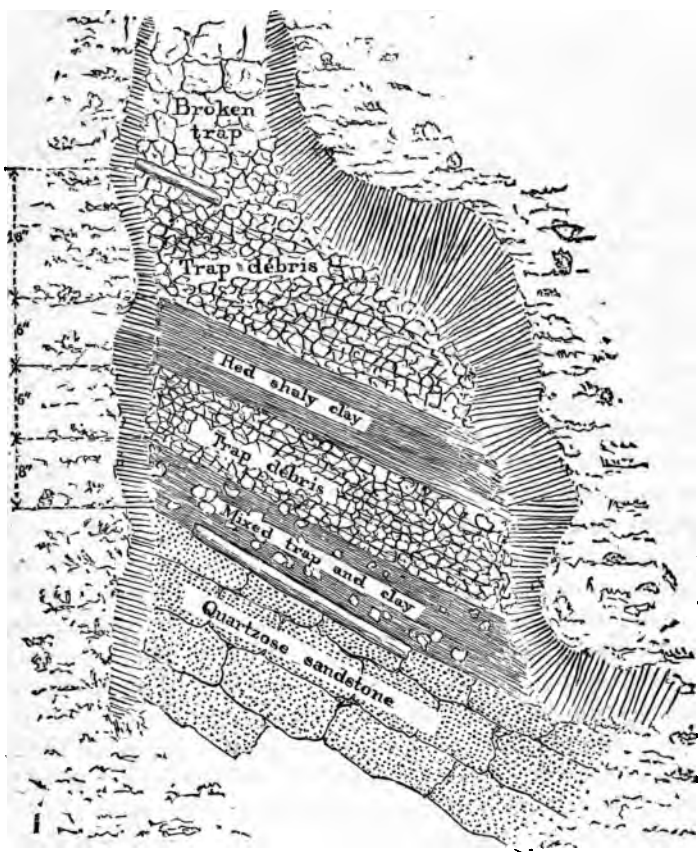


FIG. 10.—Section exposed in trench on Hungarian River, Keweenaw Point.

tion. The last one of these exposures (B of Figure 1, Plate XIV) is within a distance, measured horizontally along the bank, of fifteen feet from the first naturally exposed crumbling mass of trap. In the intervening

space, then, supposing the trappean masses mentioned to be essentially in place, as we subsequently satisfied ourselves that they are, must lie the junction between the two formations. Here our miners were set to work and three trenches were dug, as shown on Figures 1 and 2 of Plate XIV. The trench farthest up the stream (No. 1) was dug about twenty feet down-stream from an eight-foot fall over trap and amygdaloid. It started at a point two-thirds the way up the bank and extended down the slope to within about two feet of the level of the stream. Plate XV is from a photographic view of the lower part of this trench, and Figure 10 shows the relative positions of the various materials uncovered by this part of the trench. Starting from the top of the trench, *i. e.*, some feet above that portion shown in Plate XV, the following is the section laid bare:

	Ft.	in.
1. *Broken trap*, essentially in place	10	0
2. *Trap débris*: This follows the other without any definite demarkation or discernible amygdaloid. It seemed to be formed of disintegrated trap rubbed into a lumpy clay and roughly laminated. It inclines northwesterly at an angle of about 35°, and shows in that portion of the trench immediately below the uppermost of the two poles seen in the photograph of Plate XV	1	6
3. *Red shaly clay*: This is a fine-textured clay, much resembling what is known as joint clay. It is marked with light grayish-green spots, and has some sandy seams, with occasional lumps of trap. It is only in these latter particulars that it differs from a true joint clay		6.
4. *Trap débris*, similar to that above described, except that it is more mingled with non-trappean (shaly) material. It is dark colored and so contrasts with the adjoining red clay		6
5. *Mixed shaly trap debris and red clay*, with a minor element of sand; the whole of a reddish cast		8
6. *Light reddish tinted quartzose sandstone*, exposed about	2	0

The sandstone at the bottom of the trench is of the usual quartzose Eastern type, with all of the characters that we have several times noted as belonging to the sandstones of the true Eastern Series; *i. e.*, is composed, as seen in the thin section, chiefly of quartz fragments, mingled with a minor quantity of feldspar fragments and débris of the matrices of basic and acid Keweenawan eruptives, the latter occurring only sparsely scattered through a section. There is also present a small amount of interstitial oxide of iron. This sandstone is not notably hard; indeed, on its face, it is quite friable. In its body it has about the medium hardness of the ordinary Paleozoic unaltered sandstones, being far less indurated than much of the Potsdam Sandstone of Central Wisconsin. There is no evidence of unusual induration either in the hand specimen or in the thin section. On the immediate face of this sandstone, at its junction with the trap débris above it, the structure planes—which may or may not be the deposition planes, so far as we were able to determine—correspond in the main to the oblique contact face. Away from this immediate face, however, planes, in this case more evidently those of deposition, seem to dip about 10° towards the stream, or northeastward.

UPPER FALLS OF HUNGARIAN RIVER, MICHIGAN.

Figure 1, Plate

nearly

along

of the stream, or down

extends also to the bottom

may be

This that sandstone

character, and we show

point E, however, between

on the north edge of

sandstone of a wholly different

which is only very doubtfully

In the second one of the three

westward of the first, is measured

the same

The first trench

in their position

into the sandstone.

as before. Below this comes

three feet in thickness, or less

This is about six inches of the

are embraced thin sheets or

trench displays light colored

which, as before, is without

as in the case of the other

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with the adjacent

horizontal, the inclination just

The third trench showed a

the trap proper, which may

or possibly does not

seen here as before. The

to the level of the stream,

structure of the sandstone.

with those obtained in the second trench

Up-stream from the trenches to the second

ledges of diabase and diabase-amygdaloid.

exposed at the lower ledge of the

on the sides and bottom of the stream

is over a typical

farther up-stream, on the same bank,

makes exposure. The relation of the two diabase layers with the porphyry-conglomerate are perfectly plain, the conglomerate being interleaved between the two diabases and the three layers dipping at an angle of between 25° and 30° to the NW. The conglomerate is of the typical Keweenawan kind, its pebbles being in the main composed as usual of some of the Keweenawan acid eruptives. A few basic pebbles may occur near the base of the layer, an occurrence which would be in accordance with what is occasionally true with the Keweenawan conglomerates in other places. On the ground, however, we failed to detect any fragments of this kind. Of twenty-four pebbles broken at random we identified twelve as quartz-porphyry and twelve as close-textured felsite. The whole appearance of this conglomerate is very strikingly in contrast with the "mud and shingle" conglomerates of the Eastern Sandstone.

A number of photographs were taken of the exposures and trenches on the Hungarian River, some of which are here reproduced, with the object of putting the actual conditions before the reader as fully as possible. Of these Plate XVI is a view of the two falls taken from a point at about the eastern edge of the sandstone area C, shown in the bed of the stream on Figure 1 of Plate XIV. The observer is facing in a direction between west and northwest. In the bed of the stream in the immediate foreground are bowlders lying upon flat sandstone (C of Figure 1, Plate XIV). The falls just above are over diabase, which continues to the second leap of the fall, which is over conglomerate. Trench number 1, above described, lies about five feet to the left of the left edge of the view. In the water to the right of the middle foreground, and immediately at the foot of the leaning dead tree, is the peculiar sandstone already mentioned as occurring at E of Figure 1, Plate XIV. Plates XV and XVII have already been explained.

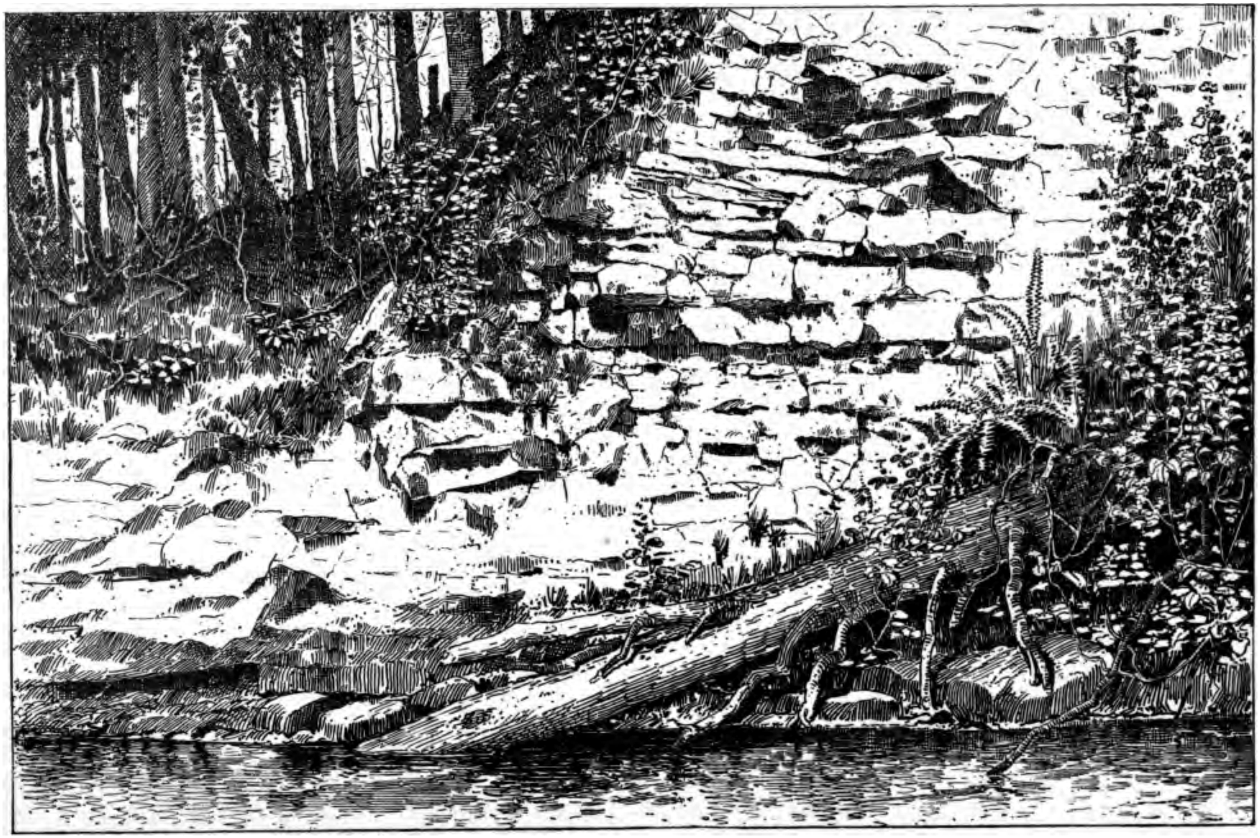
In Figure 2 of Plate XIV the relations of the exposures thus described, as also the positions of our trenches, are indicated. These exposures, together with the information obtained in the trenches, seem to us plainly to indicate the following conditions: (1) A general horizontal position for the sandstone southeast of the junction with the traps, this horizontal position continuing in places to within five to ten feet of the junction and having subordinate to it sudden bowings and bendings in different directions. As the actual junction is approached the edges of the sandstone layers appear to be crushed down so as to lie, in a general way, parallel to the junction. At and near the junction there is no undue induration. (2) Lying immediately against this crushed sandstone and inclining northwestward at an angle of about 35°, a thin seam of mingled soft red clay and trappean fragments, the whole presenting the appearance of having been rubbed together, *i. e.*, of having been the result of faulting motion. (3) Lying over this seam of junction débris, a zone of shattered trappean material whose total thickness is

In the bed of the stream, just opposite to the foot of the trench thus described, reddish sandstone is seen to cover a considerable area. The exposure C of Figure 1, Plate XIV, is partly covered by stream-drifted bowlders and pebbles, but enough of it shows to enable one to see that it lies in a nearly horizontal position. Quarrying it out, it is found to split easily along surfaces inclining perhaps 4° or 5° or less towards the axis of the stream, or down stream; *i. e.*, southeast. The flat-lying sandstone extends also to the northeast bank of the stream where (D of Figure 1, Plate XIV) it may be seen very plainly dipping eastward, at an angle of 10°. This flat sandstone, while reddish, is of the usual quartzose character, and we should say that it was unmistakably in place. At the point E, however, between this sandstone and the foot of the lower fall, on the north edge of the stream, there are little patches of a reddish sandstone of a wholly different character. This latter sandstone, which is only very doubtfully in place, is alluded to below.

In the second one of the three trenches, which lies eighteen feet southeastward of the first, as measured along the bank, we found essentially the same succession of materials as that above described to obtain in the first trench. The principal difference between the two trenches consists in their position with regard to the line of junction between sandstone and trap, the second trench covering less of the trap and extending farther into the sandstone. At the top of this trench there is broken trap as before. Below this comes dark-colored shaly trap débris about three feet in thickness, or less than in the first trench. At the base of this is about six inches of the fine-textured joint-like red clay, in which are embraced thin sheets of yellow quartzose sand. The rest of the trench displays light-colored reddish or yellowish quartzose sandstone, which, as before, is without notable induration. Next to the contact, as in the case of the other trench, this sandstone seems to dip with the plane of junction, but immediately below is seen to correspond in position with the adjacent main mass of sandstone; *i. e.*, lies within 10° of the horizontal, the inclination just here being towards the northeast.

The third trench showed a part of the trap débris at top, but did not reach the trap proper, which may perhaps lie here concealed by the drift, or possibly does not extend so far. The red clayey layer was also seen here as before. The rest of the trench was here carried down nearly to the level of the stream, chiefly for the purpose of developing the structure of the sandstone. The results were entirely in accord with those obtained in the second trench.

Up-stream from the trenches to the second fall the exposures are altogether of diabase and diabase-amygdaloid. These rocks are finely exposed at the lower leap of the falls and show more or less satisfactorily on the sides and bottom of the stream above. The upper or principal leap is over a typical Keweenawan conglomerate, which rock also shows above the upper fall on the south bank of the stream. A few steps still further up-stream, on the same bank, another diabase belt

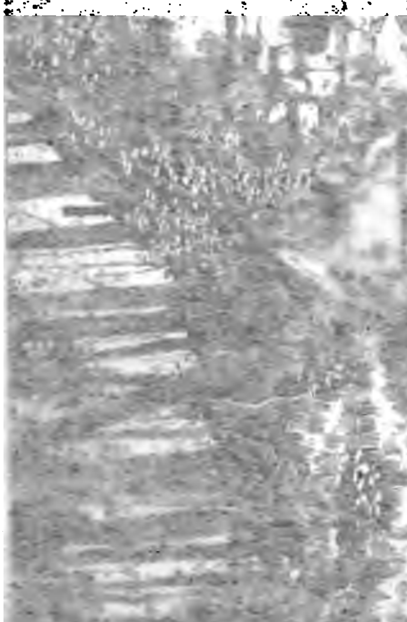


VIEW OF SANDSTONE CLIFF ON THE RIGHT BANK OF HUNGARIAN RIVER, NEAR JUNCTION WITH KEWEENAW SERIES.
[From a photograph.]

perhaps eight or ten feet; so thus thick [illegible] it is difficult to give any definite figure, since this zone grades into the débris below and into the [illegible] shattered trappean material above. (?) A [illegible] of three layers, viz, diabase, porphyry-conglomerate, and diabase, of [illegible] Keweenawan type, [illegible] northwestward at an angle of 30°, or something [illegible] than the inclination of the junction with the [illegible] sandstone.

These conditions [illegible] indicate a [illegible] motion of the Keweenawan rocks against and [illegible] the sandstone, to which [illegible] the interior [illegible] of sandstone to trap and the broken edges of the sandstone at the immediate contact, as well as its general bowed condition, are to be attributed.

We have still to allude to the sandstone masses in the bed of the river, near the south bank, at the point c of Figure 1 Plate XIV. Here, [illegible] about twelve feet below the foot of the fall, [illegible] rising a few inches from the water, and from under [illegible] the bank, is an irregular edge of a reddish sandstone of quite different appearance and character from [illegible] of the sandstone of the vicinity; for instance, [illegible] not more than ten feet away at C. It is a [illegible] compact sandstone, much fissured, the fissures [illegible] by whitish seams apparently of carbonate [illegible] which mineral also manifestly permeates [illegible] and gives it a very considerable degree of induration. Although we examined this point quite carefully, [illegible] on two different days, on one of which the water was considerably lower than indicated in the views herewith given, we were unable to convince ourselves as to whether this peculiar rock is *in situ* or is merely a drifted mass carried down by the stream from above, as have been the much larger and more numerous masses of porphyry-conglomerate which lie in the stream all about and upon the sandstone [illegible] (See [illegible] Plate XVI.) This evidently was the view held by Mr. Chauvenet at the time of his examination. In the north bank, vertically above this peculiar rock, crumbling diabase masses, probably essentially *in situ*, [illegible] But we are unable to find trappean material nearer to this sandstone than several feet. A careful study of the specimens of this rock brought away showed the body of the rock to be of a brick-red color and nearly aphanitic texture, in which compact matrix are numerous small rounded fragments [illegible]



perhaps eight or ten feet; to this thickness, however, it is difficult to give any definite figure, since this zone grades into the débris below and into the less shattered trappean material above. (4) A succession of three layers, viz, diabase, porphyry-conglomerate, and diabase, of a wholly Keweenawan type, dipping northwestward at an angle of 30°, or something less than the inclination of the junction with the Eastern Sandstone.

These conditions seem to us to indicate a sliding motion of the Keweenawan rocks against and upon the sandstone, to which motion the inferior position of sandstone to trap and the broken edges of the sandstone at the immediate contact, as well as its general bowed condition, are to be attributed.

We have still to allude to the sandstone masses in the bed of the river, near the south bank, at the point E of Figure 1, Plate XIV. Here, at a point about twelve feet below the foot of the fall, projecting a few inches from the water, and from underneath the bank, is an irregular edge of a reddish sandstone of quite different appearance and character from the rest of the sandstone of the vicinity; for instance, that not more than ten feet away at C. It is a reddish, compact sandstone, much fissured, the fissures being filled by whitish seams apparently of carbonate of lime, which mineral also manifestly permeates the rock and gives it a very considerable degree of induration. Although we examined this place quite carefully, and on two different days, on one of which the water was considerably lower than indicated in the views herewith given, we were unable to convince ourselves as to whether this peculiar rock is *in situ* or is merely a drifted mass carried down by the stream from above, as have been the much larger and more numerous masses of porphyry-conglomerate which lie in the stream all about and upon the sandstone C. (See also Plate XVI.) This evidently was the view held by Mr. Chauvenet at the time of his examination. In the north bank, vertically above this peculiar rock, crumbling diabase masses, probably essentially *in situ*, occur. But we are unable to find trappean material nearer to this sandstone than several feet. A careful study of the specimens of this rock brought away showed the body of the rock to be of a brick-red color and nearly aphanitic texture, in which compact matrix are numerous small rounded fragments of a

FIG. 11.—General section of the Hungarian Ravine, Keweenaw Point, Michigan. True scale, 700 feet to the inch.

dark-brownish to black color, the whole of the specimen being intersected by numerous white seams of dolomite. In the thin section the rock is seen to have the characters of one of the typical Keweenawan sandstones, *i. e.*, is made up in the main of felsitic débris, in larger or finer particles, mingled with which is some diabasic débris, a little quartz, a good deal of brownish ferrite, and some fine amorphous material. In addition to all of this, there is a large quantity of lime carbonate, which occurs both through the mass of the rock and in the intersecting seams in such a manner as to show that all was introduced at the same time. The lime carbonate in this case proved on analysis, contrary to expectation, to be very highly magnesian, and hence must be taken as dolomite rather than calcite. To it the induration of the rock is entirely due.

The complete difference between this rock and any of the rest of the sandstone of the vicinity, or indeed of the Eastern Sandstone formation anywhere in its entire extent, and its close similarity to the ordinary Keweenawan sandstones, leave us no choice but to regard it as either a drifted mass from the Keweenawan rocks farther west or as the projecting portion of a Keweenawan sandstone layer belonging next beneath the diabase of the lower leap of the falls. If the latter reference be correct, there is no difficulty at all in explaining the presence of a Keweenawan sandstone just here between the Eastern Sandstone and the diabase, which come together without any such intervening sandstone in the trenches on the south bank of the stream. The junction between the two formations being an irregular one, and not exactly parallel to the bedding of the Keweenaw Series, this is quite what we might expect to occur. In the ideal section of Figure 3, Plate XIV, we have suggested the latter view with regard to this indurated sandstone. The induration, on this view, is to be regarded as due to the downward filtration of lime-bearing solutions form the overhanging trap. This is of course a not very uncommon occurrence in the Keweenaw Series at the contacts of sandstones with overlying traps, and is not, to our minds, the result of contact with a heated rock, but is a mere accident of position beneath a rock capable of yielding calcareous solutions. There is nothing in the induration of this rock, then, which deters us from regarding it as part of the Eastern Sandstone, since such calcitic indurations of the sandstone might easily occur on such a junction as we have here; it is the other characters of the rock that compel us to look upon it as Keweenawan.

We have next to compare the statements of previous observers with the results of our own observations as above given.

Mr. Wadsworth's principal points with regard to the occurrences on this ravine appear to be: (1) a northwestern dip to the sandstone, which, while occasionally giving place to reverse dips, in the main shows an increase from 10° at the mouth of the ravine to 21° at the

junction; (2) the passing then of the sandstone conformably beneath the Keweenawan beds, this being proved (*a*) by the position of the sandstone vertically beneath trap at the junction and (*b*) by the induration of the sandstone next the junction, the exact junction not having been seen. An increasing northwestward dip from the mouth of the ravine to the junction is not in accordance with our own observations. As we have shown, the sandstone is often horizontal or shows dips in different directions. Moreover, while northwesterly inclinations are often seen, a general horizontal position is particularly well marked in the immediate vicinity of the junction. An inferior position of sandstone to trap in place at the junction our trenches demonstrated to be a fact. Before these trenches were dug it could have been an inference only. But this inferior position we think our observations prove to be a result of sliding motion, as they certainly prove that the sandstone does not pass conformably beneath the trap. The indurated sandstone mentioned by Wadsworth as proving that the first trap at the junction flowed over the Eastern Sandstone and indurated it is doubtless the peculiar red lime-saturated sandstone which we have described as occurring, doubtfully *in situ*, at the point E of Figure 1, Plate XIV. This sandstone Mr. Wadsworth evidently considered as certainly in place; Mr. Chauvenet thought not; but, if it is so, as we ourselves rather incline to think, its entire lithological distinctness from any other Eastern Sandstone of the immediate vicinity, or anywhere else, suffices to show that it is Keweenawan, and therefore the next layer beneath the trap at the falls just above. It would be very extraordinary indeed if a sandstone everywhere almost completely quartzose should, by heat and induration, change to one composed of felsitic débris. The dolomitic induration of this sandstone, as we have already indicated, does not present to us any reason for believing that it is due to contact with heated lava. This induration might well occur in the Eastern Sandstone at this junction, on our view of the relation of the two formations, and but for the manifest difference between it and the Eastern Sandstone generally, we should place this indurated sandstone with that formation. But we do not need to depend upon this very doubtful sandstone for proof as to the presence or absence of induration at this junction. In our trenches the junction is well displayed, and there occurs in them no such induration and no such sandstone.

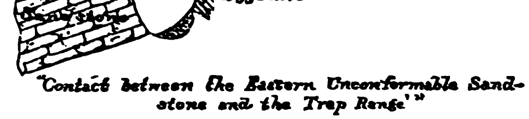
Mr. Chauvenet's descriptions, it will be seen, correspond, as far as they go, essentially with our own, the only differences worth noting resulting from the somewhat more detailed character of our own examinations, and particularly from the fact that we obtained a good deal of new information by excavating.

Dr. Rominger's description is of a more general character, but corresponds essentially with our own.

THE CONTACT AT OTHER POINTS.

Quite a considerable number of streams in addition to those followed by us cross the line of junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point. Many of these make ravines of some size, and on several we know of the occurrence of sandstones, but none of them have been examined in any detail by ourselves or others. The exposures of Keweenawan rocks on the north side of Lac la Belle, and certain conglomeratic layers in the low ground near by, indicate plainly that we are here close to the contact. When one of us examined this place in 1880, the opportunities for study were not nearly so favorable as now. The clearings for the new stamp-mill of the Conglomerate Mining Company and the numerous cuttings for the new Lac la Belle and Calumet Railroad offer tempting opportunities for study, of which we were unfortunately unable to avail ourselves. Farther west, in the vicinity of Gratiot Lake, are points exposing sandstone near the contact, as we learn from brief references in the older reports, *e. g.*, at the falls of Tobacco River, Sec. 12, T. 57, R. 31, as stated in the report of Dr. C. T. Jackson (Sen. Docs., 31st Cong., 1st sess., Vol. III, pp. 510–511). There are also similar brief references to the close proximity of sandstone and trap in Sec. 15, T. 57, R. 31 W., and on the upper part of Torch River, southeast of the Allouez mine, in Jackson's report, but in no case is there anything of sufficient importance to be worth quoting in the present connection.

One very important occurrence of a contact between the Eastern Sandstone and the traps, however, has been figured and briefly referred to by Pumpelly as obtaining in the immediate vicinity of Houghton. The accompanying figure is copied from the southeastern end of "Cross



"Contact between the Eastern Unconformable Sandstone and the Trap Range'"

FIG. 12.—Reproduced from Atlas to the Geological Survey of Michigan. Scale, 90 feet to the inch.

Section I" of the Atlas of the Geological Survey of Michigan. The exact locality of this occurrence is on the Isle Royale Mining Company's property, in the southeast quarter of the northwest quarter, Sec. 6, T. 54, R. 33 W. With regard to this place we make also the following quotations from Dr. C. Rominger, confirming Pumpelly's observation:

C. Rominger. (Geological Survey of Michigan, Vol. I, Part III, p. 96, 1873.) "The inconformable abutment of the Lake Superior sandstones against the trappean series, is in several places near Houghton plainly to be observed. One place is on the property of the Isle Royale Company, in Town 54, Range west 33, Section 6, where the top

of a ravine is formed by mighty conglomerate beds, inclosing pebbles of a porphyritic nature, besides fragments of a shaly, well stratified sandrock, and of amygdaloid trap; they dip under a high angle to the northwest, and form the terminal point of a line, on which the company, for the length of a mile, systematically had opened exploring ditches at close distances, to get accurate information of the succession of strata within this interval. Immediately against the faces of the westward inclined projecting conglomerate beds, the horizontal ledges of Lake Superior sandstone of much lighter color than the sandstones connected with the conglomerates are seen abutting in the bed of the small creek which runs through the ravine.

* * * * * * *

"A large patch of horizontal sandstones overlies unconformably the trap rocks on top of the hills near Houghton, on the Sheldon and Columbia property. I am not absolutely certain whether it came there as a huge drift mass or whether it is the remnant of deposits which were there in their original position, but I am inclined to the last opinion (p. 96).

Contacts similar to that at Bête Grise are known to occur at several points on the south edge of the trap range in the vicinity of the Ontonagon River. One of these was examined in detail by Mr. Chauvenet in 1880. Unfortunately the note-book containing his quite detailed description is no longer extant. An abbreviated account of this occurrence was given by one of us in the work heretofore quoted, along with a reduced copy of Mr. Chauvenet's general section. The following is this description:

R. D. Irving. (Copper-Bearing Rocks of Lake Superior, Monographs United States Geological Survey, Vol. V, pp. 359–360, 1883.) "The above section was taken by Mr. W. M. Chauvenet along the course of the small stream in Sections 23 and 24, T. 50, R. 39 W. The sandstone seen here is the usual saccharoidal quartzose kind, often perfectly white, and at times mingled and streaked with more or less brownish material. It carries frequent pebbles of white quartz, but none of the Keweenawan diabase against which it rests. One mile south, in section 27, the sandstone was observed in a horizontal attitude, and in the S.W. ¼, Sec. 28, was seen in large exposures at the falls of the Ontonagon River. Here it dips southward at an angle of 15°, but as it is followed northward some 200 yards this dip changes to 18° and 20°. A short distance farther north is a bold south-facing bluff of Keweenawan diabase. It should be said that these south dips are not wavering and uncertain, like those observed on the Douglass Houghton River, but are persistent and pronounced, affecting many hundred feet in thickness, while the exposures are to be likened in extent and inclination to those seen on Bête Grise Bay."

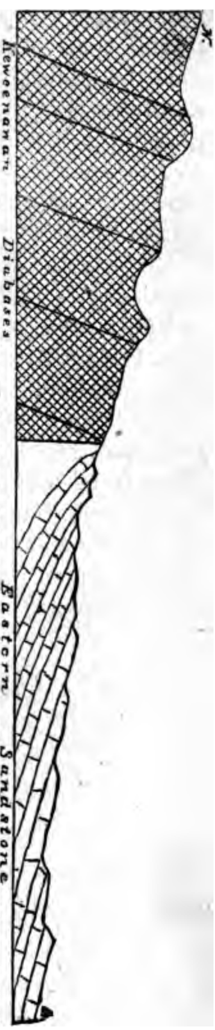


FIG. 13.—Section showing relation of Eastern Sandstone to Keweenawan diabase, T. 50, R. 39 W., Michigan. Length of section, one half mile.

The exact contact of the trap and the sandstone were not seen by Mr. Chauvenet, but the two were found within a few feet of each other and he describes the whole occurrence as most marked

and unmistakable. It is to be noted that the Eastern Sandstone preserves here its usual quartzose character and that it is just here without included red shale or conglomerate.

In the same connection reference should be made to the very interesting and peculiar occurrences which have been described by Mr. E. T. Sweet as obtaining along the contact of the south-dipping traps and the "Western" horizontal sandstone in the northern part of Douglas County, Wisconsin, which two formations are the equivalents respectively of the north-dipping traps and "Eastern" horizontal sandstones of Keweenaw Point.[1] The similarity between the occurrences described by Mr. Sweet and those of the Douglass Houghton and other ravines on Keweenaw Point was noted by one of us some years since.[2] Our recent examinations have impressed this similarity upon us yet more strongly, and we can have little doubt that they are due to entirely similar and not improbably contemporaneous causes.

[1] Geology of Wisconsin, Vol. III, Part V, pp. 340–349; also Copper-bearing Rocks of Lake Superior, Monographs United States Geological Survey, Vol. V. pp. 252, 258.

[2] Ante, p. 56.

II.—DISCUSSION OF VIEWS; CONCLUSIONS.

In this part we give, in chronological order, and in the words of those who have advocated them, the various hypotheses that have been advanced with regard to the relations of the Eastern Sandstone and the trappean series, with some comments of our own in each case. Each of these hypotheses we call after the geologist who seems first to have proposed it. We then close with our own views upon this question.

THE JACKSON VIEW.

C. T. Jackson. (Senate documents, Thirty-first Congress, first session, 1849–'50, Vol. III, pp. 398, 399.) "The red sandstone and conglomerate rocks of Keweenaw point existed there anterior to the elevation of the trap rocks, and were produced by the deposition of fine sand and pebbles derived from pre-existent primary rocks—such as granite, gneiss, or mica slate. Porphyry furnished a large proportion of the debris, but it is doubtful whether it is not a metamorphic rock, resulting from the semifusion of the finer materials of sandstone. It is evident at once, from inspection of the pebbles of the conglomerate, that they have been ground into their present shape by long attrition under water or upon some ancient shore. They are oval and rounded, and are of various magnitudes, from that of a buckshot to the size of a man's head. They originated from some nether rock or were transported to their present location by drift agencies—this locality not exhibiting any rock they could have been derived from, in place. If they were transported bowlders, like those of the more recent drift, they would seem to indicate the existence of ice immediately after the coal era—an opinion difficult to establish, it being counter-indicated by the fossils of that epoch.

"There is no reason to believe that igneous agencies had anything to do with the origin of the pebbles of the conglomerate, for they bear ample proofs of their having been rounded by the action of water. From the circumstance that the conglomerate borders the trappean rocks it is supposed that an ancient shore may have existed along that line, or that, during the upheaval of the trap and before the materials of the sandstone were indurated into masses, the reflux of the water may have carried away the fine sand into deeper water and left the pebbles near the uprising trap. It is certain that the finer sandstone is more remote from the trap than the conglomerate is, and that it is less uplifted and inclined as it recedes from the trap band. Thus, at and near the junction of the two rocks, the strata dip 25° or 30°, while remote from it the sandstone strata are horizontal, or only slightly waved. Sandstone was certainly deposited in water, for the ripple marks are well preserved and record this fact in an absolute manner, for we at once recognize the well-known action of water on sand. By pressure and heat the materials of a loose shifting sand became converted into solid sandstone, the layers of sand forming the different strata. At first the whole must have been in horizontal or nearly horizontal layers; for water necessarily deposits mechanical sediment in this manner, and the only slopes of deposition would be on the shores, where a very moderate inclination would take place, but much less than we find it to be where the strata have been disturbed by the trap rocks which caused the elevation of the sandstone along the line of its disruption."

FIG. 14.—Ideal section of Keweenaw Point, on the Jackson view. Scale, 2 miles to the inch.

C. T. Jackson. (Final Report on the Geology, Topography, and Mineralogy of Lands around Lake Superior, Senate documents, Thirty-second Congress, first session, 1851, p. 328, Vol. XI, No. 112.) "At Lac la Belle and at Mt. Houghton the trap rocks occur, and ride over the sandstone strata after passing between their layers; and at Mt. Houghton the igneous agency of this trap rock has changed the fine sandstone into a kind of jasper.

As we understand them, Jackson's views were as indicated in the following summary: (1) The Eastern Sandstone and the conglomerates and sandstones of the copper-bearing series are one and the same formation, and were once spread out continuously in a horizontal position; (2) the traps of the copper-bearing series are all of them intrusive, having invaded the supposed sandstone formation in part as irregular intersecting masses and in part in the shape of sheets which forced their way between the sandstone layers; (3) the conglomerates of the copper-bearing series derived their material by the ordinary aqueous agencies from some subjacent formation, which possibly may have formed an old shore line in the immediate vicinity of Keweenaw Point. More probably, however, the pebbles of the conglomerate have been sorted out, as it were, from the previously existing sand beds by the violent currents set in motion at the time of the trappean intrusions; (4) the inclination *southeastward* in the Eastern Sandstone at the junction with the traps, and that to the *northwestward* of the sandstone and conglomerates of the copper-bearing series, are due to the intruding trap.

The contemporaneous or lava-flow origin of the traps of the copper-bearing series having been since so repeatedly and abundantly demonstrated, there is no reason that we should attempt any further refutation of Jackson's position as to their intrusive character. We can conceive of the Eastern Sandstone passing conformably beneath the copper series, or of its having once been continuous with the uppermost member of the series from which it is now faulted away; but the lava-flow origin of the trap being once admitted, it is sufficiently evident that on no possible structural hypothesis can the Eastern Sandstone and the Keweenawan sandstones and conglomerates be regarded as having once formed a continuous series. There are, of course, abundant other reasons why Jackson's hypotheses cannot be accepted, among which we need now only allude to the entire contrast between the Eastern Sandstone and the Keweenawan detrital rocks, both as to lithological characters and relative thicknesses.

In the accompanying diagram we have attempted to

illustrate—on a cross-section of Keweenaw Point, drawn to a true scale, and indicating the true widths of the Eastern Sandstone and the copper bearing rocks—the views maintained by Jackson. It is, of course, possible that we may in some respects misunderstand and misrepresent him.

THE FOSTER AND WHITNEY VIEW.

J. W. Foster and J. D. Whitney. (Report on the Geology and Topography of a Portion of the Lake Superior Land District, Part I, Copper Lands. House Document, Thirty-first Congress, first session, 1849–'50, No. 69.) "*Southern trap range.* Returning to the head of Keweenaw Point, we find another range of trap, forming the southern boundary of the valley of the Little Montreal river and stretching westerly in a line nearly parallel with the northern chain. This is known as the Bohemian range, and differs from the northern both in lithological character and in the mode of its occurrence. While the former, before described, is composed of numerous beds of trap, in the main of the amygdaloid and granular varieties, interstratified with the detrital rocks, the southern range consists of a vast crystalline mass, forming an anticlinal axis, flanked on the north by the bedded trap and conglomerate and on the south by conglomerate and sandstone.

"The contour of the unbedded trap is also very different from that of the bedded trap. We nowhere recognize the stair-like structure in the hills; they are either dome-shaped or rounded.

"The protrusion of so vast a mass of heated matter has changed in a marked degree the associated sedimentary rocks, causing them to resemble igneous products. Thus, on section 30, township 58, range 27, by the lake shore, is seen a metamorphosed sandstone resembling jasper. Its general bearing is east and west. In places it assumes a vesicular appearance, while other portions are brecciated and take into their composition chlorite and feldspar. In some hard specimens the lines of stratification can be recognized. The mass is about 100 feet thick, and surmounted by alternating bands of porphyry and a chlorite rock known as rotten trap, which may be regarded as a volcanic ash. These veins attain a thickness of only a few feet. Proceeding along the southern coast of Keweenaw Point in a westerly direction, at the old fish station (section 35) we again observe this metamorphosed rock forming one of the jutting points of the bay; but here it assumes a different character, as though it had been subjected to a heat more intense and longer continued. All traces of stratification have disappeared, and the rock has become transformed into a red, compact jasper, breaking with a conchoidal fracture and traversed by numerous divisional planes. Where it comes in contact with the trap below it presents a homogeneous texture. All traces of its mechanical origin are obliterated, and it is difficult to determine where the igneous rock ceases and the aqueous begins (pp. 64–65).

* * * * * * *

"The following section, from Copper Harbor to Lac la Belle, exhibits not only the contours of the country but the relative association of the detrital rocks and the bedded and unbedded trap:

"The Bohemian range, as before remarked, forms the line of upheaval of the bedded trap and conglomerate on the north and the conglomerate and sandstone on the south. The conglomerate north of the axis of elevation rarely attains a greater inclination than 45°, but on the southern slope the sandstone is observed dipping at an angle of 78°. This is beautifully exhibited by the lake shore, on section 36,[1] town-

[1] Probably a misprint for 26, since there is no section 36 in this township.

ship 58, range 29. The sandstone is seen in the bottom of the bay, composed of alternating bands of white and red, sweeping round in curves, conformable to the course of the trappean rocks. As we recede a few miles to the south, the strata are observed

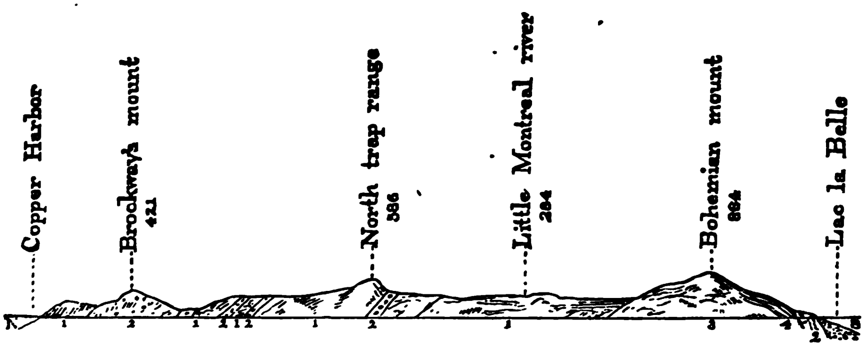


FIG. 15.—Section of Keweenaw Point from Copper Harbor to Lac la Belle. (Reproduced from Foster and Whitney.)

1. Brown granular trap, occasionally crystalline; 2. conglomerate; 3. Labrador and chlorite rock; 4. chlorite (fissile).

to be nearly horizontal. In the two adjoining townships west this range preserves its distinctive character, but beyond it sinks down into sloping hills 200 or 300 feet in height (p. 66).

* * * * * * *

"In the region of Portage lake, the shock by which the bedded trap and conglomerate were elevated, does not appear to have been attended with the protrusion of vast crystalline masses forming a long range, like the Bohemian mountains, or rounded groups, as in the vicinity of the Ontonagon, but simply to have caused a vertical dislocation, lifting up the beds on one side of the fissure while the corresponding beds on the opposite side remained comparatively undisturbed. There can be no doubt that there existed a deeply seated and powerful fissure extending from the head of Keweenaw Point to the western limits of the district, along the line of which the volcanic forces were, at different times, powerfully exerted—similar in character to those in Guatemala, Peru, and Java—the seats of modern volcanic action.

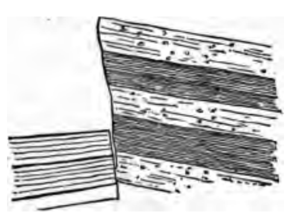


FIG. 16.—Junction of Eastern Sandstone and trappean series. (Reproduced from Foster and Whitney.)

"The only instance observed in this part of the district, of trap occurring remote from the line of the fissure is in the northeast corner of township 49, range 36, 14 miles southwest of the head of Keweenaw bay. It is known as Silver mountain, (*lucus a non lucendo*,) which rises up isolated and dome-shaped to the height of a thousand feet, and occupies an area equal to three sections (p. 68).

* * * * * * *

"*Sandstone.*— It is not our purpose in this report to set forth the boundaries of the sandstone, much less to describe its characters, where it comes in contact with the pre-existing rocks. These descriptions will be reserved for the general report on the paleozoic rocks of this district. We propose simply at this time to show its connexion with the cupriferous rocks before described. In order that this connexion may be better understood, we introduce the following diagram:

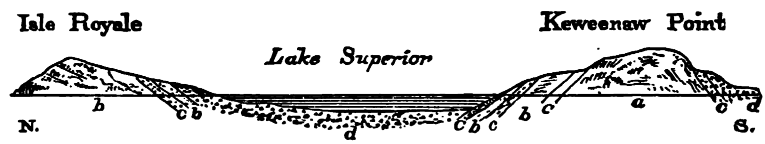


FIG. 17.— Section from Isle Royale to Keweenaw Point. (Reproduced from Foster and Whitney.) *a a*, crystalline trap; *b b*, bedded trap; *c c*, conglomerate; *d d*, sandstone.

"We have seen that, during the deposition of the sandstone, numerous sheets of trap were ejected and flowed like lava-streams; and that the igneous and aqueous products were so intermingled as to present the appearance of having been derived from a common origin; and that subsequently the unbedded trap broke through these parallel fissures, lifting up the sandstones, conglomerates, and bedded traps, and causing the whole mass to dip at high angles. Thus, this portion of the bed of Lake Superior is due to these two lines of upheaval. The sandstone between the two lines performs an immense curve, portions of which are at least 800 feet below the chord formed by the surface of the water. The sandstone is seen on Isle Royale, forming the outer reefs of Siskawit bay (pp. 109, 110).

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"Passing over the trappean ranges we find the sandstone occupying the southern slope and bearing the same relation to the trap as the northern belt, with this exception, that the intervening masses of conglomerate are in the main wanting" (p. 112.)

J. W. Foster and J. D. Whitney. (In a paper on the Age of the Sandstone of Lake Superior, with a Description of the Phenomena of the Association of Igneous Rocks. Proceedings American Association for the Advancement of Science, Cincinnati meeting, 1851, pp. 22–38.) "In the vicinity of the trappean rocks, on the other hand, we find the sandstone developed to a great thickness and accompanied by wide belts of conglomerate; we find it becoming impregnated with oxide of iron and calcareous matter and intersected by numerous veins of calc-spar and baryta, and containing native copper and its ores; we find it interstratified with beds of igneous rock, in numerous alternations, which beds have successively flowed over its surface and been again covered by sedimentary material; we find the whole system of conglomerate, sandstone and bedded trap, lifted up at an angle which gradually increases as we approach the central igneous mass and from which it dips on each side (pp. 29–30.)

* * * * * * *

"Returning to the head of Keweenaw Point, we find another range of trap, forming the southern boundary of the valley of the Little Montreal River and stretching westerly in a line nearly parallel with the northern chain. This range differs from the other, both in its lithological character and in its mode of occurrence. While the northern range, as before described, is made up of numerous beds of trap, in the main, of the amygdaloidal and granular varieties, interstratified with the detrital rocks, the southern range consists of a vast crystalline mass, forming an anticlinal axis, and flanked, on the north, by the bedded trap and conglomerate, and on the south by the sandstone and conglomerate (p. 31).

* * * * * * *

"The conglomerates of Keweenaw Point, and Isle Royale, consist of rounded pebbles and masses of trap, almost invariably of the amygdaloidal variety, derived, probably, from contemporaneous lavas, and rounded fragments of a jaspery rock, which may have been a metamorphosed sandstone; the whole cemented together by

a dark red ferruginous sand. This cement may be regarded as a mixture of a volcanic ash and arenaceous particles; the latter having been derived from the sandstone then in the progress of accumulation. It is not unusual to meet with strata composed entirely of arenaceous particles associated with the conglomerate beds, and when these expand to a considerable thickness, the associated sandstone appears in alternating bands of red and white, and exhibits few traces of metamorphism: but when the belts of sedimentary rock are thin, and come in contact with the trappean rocks, the sandstone is converted into jasper, and becomes traversed by divisional planes.

"We are strongly inclined to the belief that the origin of the conglomerate is not due, solely, to the action of waves and currents which have broken up and rounded and polished, the trappean and jaspery masses of which it is composed: on the contrary, we believe that the greater portion of these immense deposits are the result of an igneous, rather than an aqueous force. The rounded masses, in the conglomerate, often attain a magnitude of 18 inches in diameter, and their surfaces do not always present that smooth and polished appearance which results from the attrition of water. In fact, a close observer can, in most cases, readily distinguish between those pebbles which have been recently detached from the rock, and those which have been, for a time, exposed to the action of the surf. The conglomerate seems to have been formed too rapidly to allow of the supposition that their origin was purely aqueous; for while the contemporaneous sandstone, remote from the line of volcanic action, does not exceed 300 or 400 feet in thickness, the united thickness of the conglomerate bands, in the vicinity of the trap of Keweenaw Point, exceeds 5,000 feet. As we recede, for a few miles, from the igneous rocks, the conglomerates disappear, entirely, as separate members of the formation, and are only found in very thin and insignificant patches, amidst the sandstone.

"We have little hesitation, therefore, in adopting the views of Von Buch, as to the origin of such masses of rounded materials in the vicinity of igneous rocks, and consider them as the result of the friction and mechanical action caused by the volcanic action along the line of fissure. We can hardly conceive of the displacement of such enormous masses of igneous matter as have, during a long period, been flowing over the depositing beds of sedimentary matter, without supposing violent dislocation and crushing of the previously deposited strata. Immense quantities of material would be loosened, and torn off, along the line of volcanic outburst, and would gradually become rounded by friction against each other. Those pebbles which have a vesicular structure may have been ejected as scoriæ, while in a semi-fluid state, and have received their rounded form while falling through the air, like volcanic bombs. Whether it be allowed, or not, that such conglomerates could have been produced, solely, by igneous or volcanic action, it must be evident to every one that in this way materials would be heaped together, and broken up so that under the action of strong currents of water they would soon assume a rounded form. In fact, these very currents must have been caused, or increased vastly in intensity, by the same volcanic action which produced the igneous rocks (pp. 32, 33).

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"Where the Bohemian range breaks through the incumbent rocks at Lake La Belle, a thin band of conglomerate is observed, not exceeding 30 feet in thickness, and which has been traced at intervals for two or three miles. The inclination is 80° to the south and south-east. The whole mode of action of the dynamic forces on the north and south side of the trap range, seems to have been different. On the north side, we not only find the bedded trap, and immense deposits of conglomerate above described, which rarely occur on the south; but we have a material difference in the character of the dip of the sandstone in the two slopes. On the north, the sandstone and conglomerate dip at angles rarely exceeding 40° in the immediate proximity of the trap, and this dip gradually diminishes as we recede from the center of elevation, so that a gently descending slope is formed, which extends regularly from the highest point

of the igneous rocks to the lake shore. This is particularly the case to the east and west of the Ontonagon, where the descent of 400 or 500 feet from the trap to the lake, is so gradual and regular as to be hardly perceptible. The mural faces of the trappean ranges are almost without exception turned toward the south, and we find the sandstone on that side elevated at a high angle, dipping almost vertically sometimes, just at the junction of the two formations, but as we proceed southward, almost immediately becoming horizontal again. The appearance is as if the strata had been broken and elevated just at the southern edge of the igneous mass; while but at a short distance from it, in that direction, no disturbing force was acting during their deposition. To account for this phenomenon we must suppose that the line of igneous activity was along the northern edge of the trappean range, and that afterward, during the protrusion of the more southern portion of the trap, that of the Bohemian Mt. or Keweenaw Pt. for instance, the up-heaving action was confined principally to the region on the north. Thus, while a gradual elevation of the bedded trap and conglomerate was going on just north of the central fissure, a corresponding depression was taking place still farther north, and the reverse of all these circumstances was taking place in the line of Isle Royale. The great synclinal trough, or basin, of Lake Superior was the result of this combined action of elevation and depression (p. 35)."

J. D. Whitney. (In The Metallic Wealth of the United States, 1854, pp. 251, 252.) "The sandstone of Lake Superior, in regard to the geological position of which there was formerly some disagreement, has now been satisfactorily determined to be of Lower Silurian age, and probably the equivalent of the Potsdam Sandstone, the lowest fossiliferous rock recognized in this country. Above it, as we proceed southward from any point between Sault Ste. Marie and the Pictured Rocks, we find the upper members of the Silurian system cropping out in succession, with a slight southerly dip. Along this portion of the Lake the sandstone lies nearly horizontally, and is made up of rounded grains of quartzose sand but slightly colored by iron and having little coherence, and the whole thickness does not seem to exceed 300 or 400 feet. Where it comes in contact with the older azoic rocks, as may be observed in the vicinity of Carp and Chocolate Rivers, it is seen resting unconformably upon them, having been deposited nearly horizontally on their upturned edges. On Keweenaw Point, however, its character is entirely changed; it has increased greatly in thickness, is tilted up at a considerable angle, and is associated with very heavy beds of conglomerate and trappean rock.

* * * * * * *

"The rocks of which the trap range is made up are somewhat varied in their mineralogical character but they belong mostly to the igneous class, and it is apparent, from their mode of formation and position, that they were poured out from the interior of the earth, at the time the deposition of the sandstone was going on, from a series of fissures which extended along the line now occupied by the metalliferous formation. In the more elevated and central portion of the range, the igneous rocks predominate, containing intercalated beds of conglomerate, of very inconsiderable thickness, between heavy masses of trappean rock. As we recede from the line of igneous action in either direction, we find that the belts of trap become thinner, the conglomerate predominates, but gradually disappears, and is succeeded by the sandstone with its normal character. Thus the appearance of the conglomerate is seen to be allied with and subordinate to that of the igneous masses, and it appears to have been a result of the combined action of the two classes of agencies by which the trap and sandstone were formed. The whole system of the bedded trap and the interstratified masses of conglomerate is developed on a grand scale, some of the single beds acquiring a thickness of several thousand feet.

* * * * * * *

"Thus in the Bohemian or Southern range of Keweenaw Point, which appears to have been protruded at a late epoch, and under different conditions, and to have tilted up the system of the bedded trap and interstratified conglomerate which lies to the north, the veins bear only sulphuret of copper" (pp. 254-255).

After carefully re-examining the various extracts above given from Messrs. Foster and Whitney, we feel less confident than formerly that we thoroughly understand their theoretical position. As nearly as we are able to gather their meaning, however, it is about as follows: (1) The Eastern Sandstone and the Keweenawan detrital rocks are one and the same formation. (2) The associated igneous rocks are of two classes as to time and mode of eruption: (*a*) those traps which are interleaved with the detrital rocks were formed at the surface during the accumulation of those rocks, *i. e.*, are of lava overflow origin; (*b*) the traps of the Bohemian Range, which are held to lack the bedded structure, were intruded in great masses at a time entirely subsequent to the formation of all of the sandstones, Eastern as well as Keweenawan, and of all of the interleaved trappean flows. (3) To the eruption of the supposed unbedded trap of the Bohemian Range is to be attributed the northward inclination of the Keweenawan rocks on the north of this range and the southward inclination of the Eastern Sandstone on the south of it. To this intrusion also is to be attributed the formation from the previously existing sandstone of "jasper" masses, such as that of Mount Houghton and the Bare Hills on the north side of Bête Grise Bay. (4) The conglomerates of the trappean series are in large part of igneous origin, the rounding of the pebbles being due not to water action, but to "friction of the elevated rock against the walls of the fissures." These conglomerates are composed chiefly of rounded pebbles of trap and subordinately of a jaspery rock. If not directly due to igneous causes, the rounding of the conglomerate pebbles may have been partly produced by the violent currents caused by the igneous outflows. To the production of these conglomerates by eruptive agencies is to be attributed the immensely increased thickness of the detrital portion of the formation in the region of Keweenaw Point as contrasted with its thickness farther to the eastward on the south shore of Lake Superior. (5) The various bedded eruptives of Keweenaw Point reached the surface through a series of fissures along the course of the Point. (6) The massive trap of the Bohemian Range, however, was extruded along an immense fissure formed subsequently to and to the south of those through which the bedded traps reached the surface. This immense fissure extended, however, far to the westward of the Bohemian Range intrusion, along what is now the southern edge of the trappean formation and the northern edge of the Eastern Sandstone, reaching as far as the neighborhood of Lake Gogebic. To the southwest and west of Torch River on Keweenaw Point and until the vicinity of the Ontonagon is reached, the production of this fissure was unaccompanied by any igneous outflow. Along this portion of the fissure the bedded traps and interstratified detrital rocks, dipping to the northward, come directly against the horizontal beds of the Eastern Sandstone.

In addition to the conclusions above enumerated, it seems, although

we do not find such a view exactly stated in their works, that Messrs. Foster and Whitney must have believed also in a former continuity of the Eastern Sandstone with the uppermost sandstones of the copper-bearing series on Keweenaw Point, from which it was faulted away during the production of the fissure above alluded to. It would seem that they must also have considered that, before this fissuring, the bedded traps and conglomerates had an approximately horizontal position.

We have already given three sectional diagrams copied directly from Messrs. Foster and Whitney's reports illustrative of their views. These diagrams are, of course, not drawn to any definite scale. Herewith we give two cross-sections of Keweenaw Point, drawn to a true scale, in which we have embodied their views as to the structure here obtaining as well as we are able.

As confirmatory of a former continuity between the Eastern Sandstone and the uppermost sandstones of the copper-bearing series, there has of late years been cited a lithological similarity, the remaining sandstones of the Keweenaw Series being quite strongly contrasted lithologically with the quartzose Eastern Sandstone. A somewhat more careful examination of this alleged similarity, however, shows us that it depends almost entirely upon certain sandstones which occur in

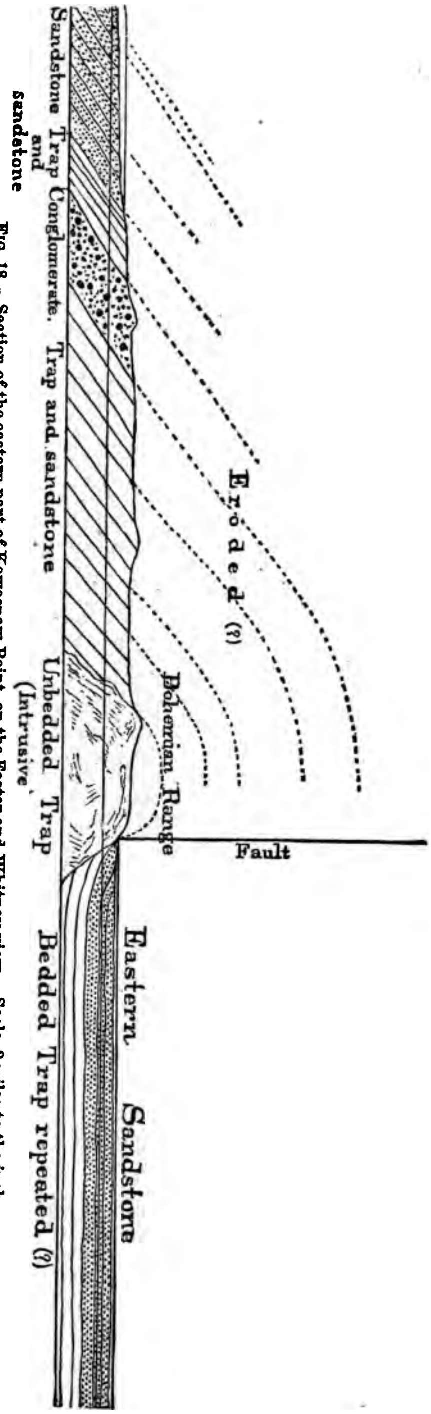

FIG. 18.—Section of the eastern part of Keweenaw Point, on the Foster and Whitney view. Scale, 2 miles to the inch.

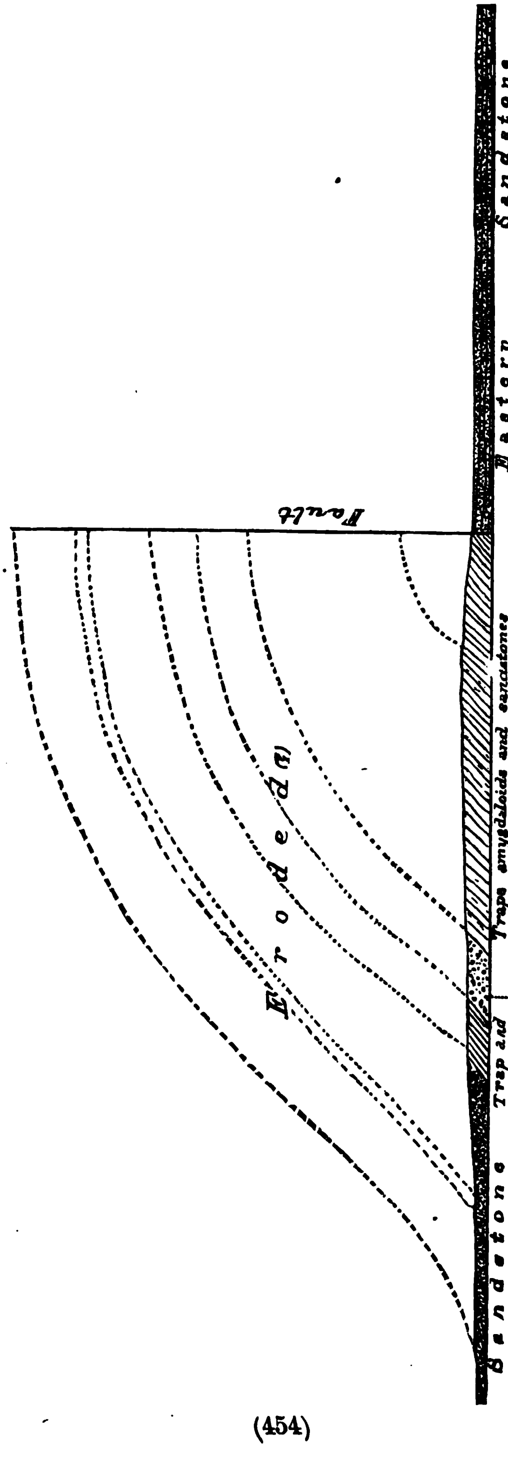

FIG. 19.—Section of the western part of Keweenaw Point, on the Foster and Whitney view. Scale, 2 miles to the inch.

quite flat positions along the shore of Lake Superior, between the Portage Entry and the Ontonagon River. These sandstones, which from their position it is certainly natural that we should regard as the uppermost part of the Keweenaw Series, are without doubt much more quartzose than any that we have yet studied from the remainder of the extent of that series. If we may judge, however, from thin sections recently made of the most quartzose portions of the exposures near the mouth of the Portage Canal, they are never so completely quartzose as the Eastern Sandstone, from which they differ, also, in the angularity of the particles. Small, rather angular particles of quartz and feldspar, the former often secondarily enlarged so as to fit closely, make up most of the sections of the sandstone near the Portage Canal. In addition to these ingredients there are fragments of a complex character, now apparently mainly composed of chloritic and kaolinic material, but which are perhaps representative of some of the Keweenawan basic rocks. There is also a quite plentiful oxide of iron cement. It is to be observed that this sandstone, even on the view of the entire distinctness of the Eastern Sandstone and the Keneewaw Series, might as well be placed with the former formation as with the latter. There being always a wide covered space between it and the undoubted Keweenawan rocks, its relation to them is matter of inference only. It does not seem an impossible hypothesis that this sandstone may be an eastern continuation of the horizontal sandstone of the Apostle Islands.[1]

On account of the doubt which thus hangs over the true position of these sandstones, we have studied in this connection a number of sandstones unquestionably from the upper horizons of the Keweenaw Series, selecting always those localities promising the most quartzose kinds. The results are as follows: (1) The sandstone from the bed of Carp River, southwest quarter Sec. 19, T. 51, R. 42 W., in the Porcupine Mountains, gives a section which is made up chiefly of exceedingly fine angular fragments of quartz and feldspar, the latter predominant, the quartz not forming more than one-third of the section. Various complex fragments, more or less decomposed, of basic and acid rocks are present, also a considerable portion of indurating quartz and calcite, and oxide of iron cement (slide 631). This rock is from the Inner Sandstone of the Porcupine Mountains.[2] (2) From the Outer Sandstone of the Porcupine Mountains, which has been selected by one of us as the lowest part of the upper division of the Keweenaw Series, we have examined a rock obtained at Carp Lake Landing, which gives a section composed mainly of fragments of felsitic porphyry matrix, granitic porphyry, and of individual feldspars and quartzes, the latter sharply angular and very small. A large part of the section is composed of calcite (slide 652). (3) A sandstone from a lower horizon, in the southeast

[1] See Monographs United States Geological Survey, Vol. V, Plates I, and XXIII.
[2] Ibid., Plates XIX, XX, and XXI.

quarter of Sec. 14, T. 50, R. 45 W., is grayish, much indurated, and of fine grain, and gives a section of about the same sort, the proportion of fragmental quartz being very small. Most of the quartz of the specimen is infiltrated or indurating quartz (slide 351). (4) From a higher horizon come certain sandstones at and near the mouth of Carp River. These are dark reddish-brown or yellow, and feebly indurated. The principal constituents are fragments of porphyry matrix, detritus of basic rocks, and sharply angular feldspar and quartz fragments. The quartz does not form more than one-tenth to one-fifth of the section. Quite a large proportion of iron oxide cement is present (slide 2161). (5) Quite closely similar to the last described is the thin section of a rock from a much higher horizon, viz, the main sandstone mass of the upper division of the Keweenaw Series as exposed in the bed of Presque Isle River, northeast quarter Sec. 5, T. 49, R. 45 W. (slide 355). (6) At a still higher horizon—indeed the very highest with which we are acquainted, if we exclude the doubtful sandstone on the lake coast between the Portage Canal and the Ontonagon River—lies the sandstone at the mouth of the Montreal River. Of this sandstone two sections representing different phases were studied. One of these is a dark reddish-brown, coarse-grained, friable rock, containing numerous mica flakes. The main constituents of the rock are quartz and feldspar in sharply angular fragments, fragments of porphyry matrix, and magnetite fragments. Both quartz and feldspar grains have received quite strongly-marked enlargements.[1] Besides the complex particles certainly referable to acidic Keweenawan eruptives, others occur which are as plainly referable to the basic eruptives. Muscovite flakes are somewhat plenty. The quartz fragments of this rock, whose angularity is somewhat striking, are more plentiful than in any other undoubted Keweenawan sandstone examined, but they yet form only a minor portion of the whole section (slide 2193). The other rock from the same vicinity on Montreal River is also very coarse grained, but is light colored, the feldspar fragments being quite noticeable to the naked eye. In the thin section these feldspar fragments are seen to make up fully one-half the mass of the rock. These fragments are at times quite fresh, although commonly they are more or less thoroughly decomposed. They include both orthoclase and plagioclase. Of the remaining portion of the rock, about one-half is made up of complex fragments of basic and acid Keweenawan rocks, with greenish and reddish decomposition-products and iron oxide cement. The balance of the rock, not more than one-fourth of the whole, is composed of quartz fragments, mostly simple, but in a few cases finely complex. The simple grains of quartz have frequently received secondary enlargements, to which cause the slight induration of the rock is plainly due (slide 2190). Precisely similar rocks to the last described, and

[1] See Bulletin United States Geological Survey No. 8.

belonging to an equally high horizon, are those (7) of Leihy's Falls, on Bad River, Ashland County, Wisconsin, Sec. 25, T. 47, R. 3 W., and (8) at Welton's Dam, on White River, in the same county, N. E. ¼, Sec. 6, T. 46, R. 4 W. (slides 2191, 2192).[1]

Thus, after selecting the most quartzose varieties of the upper Keweenawan horizons for comparison, we find them yet very strikingly different from the Eastern Sandstone itself, they being always greatly leaner in quartz and having as chief constituents the detritus of the acid eruptives of the Keweenaw Series, to which category the quartz fragments of these sandstones may well themselves belong. The striking angularity of these quartz fragments, as compared with the almost universally well-rounded fragments of the Eastern Sandstone, is worthy of note. The view that the Eastern Sandstone has been faulted away from the outermost layers on Keweenaw Point does not, then, receive the corroboration that might have been expected from our microscopic studies; on the contrary, the results are quite against it.

With regard to the other points in the views of Messrs. Foster and Whitney, we have to say, in the first place, that we are unable to accept their division of the trappean rocks into the two prominent classes of intrusive and contemporaneous. We do not mean to assert the entire absence of intrusive eruptives on Keweenaw Point; it would be natural enough that such should occur. We have, however, been unable to recognize any intrusives other than certain reddish granite-like acid rocks of the Bohemian Range. All of the trappean beds of the point, so far as we have seen them, are plainly of lava-flow nature. Nor do we find any proof whatever in the writings of others of the existence here of intrusives. The Bohemian Range of Keweenaw Point (which Messrs. Foster and Whitney speak of as a great intrusive mass and as having by its intrusion tipped up the alternating lava-flows and sand beds to the north of it and the sandstone to the south) one of us examined with some care several years since in the vicinity of Lac la Belle, along the shore of Bête Grise Bay, and again to the southeast of Eagle River. What he saw in this examination served to convince him that the Bohemian Range was in general character like the more northern rocks, being made up of a succession of lava-flows with here and there interstratified conglomerates. Certain rocks of this range, which appear somewhat different from those farther north, are just such as are to be seen at similar low horizons throughout the geographical extent of the Keweenaw formation; while interstratified with these and predominating over them are various traps and detrital rocks in no way

[1] Geology of Wisconsin, Vol. III, pp. 202–203. For descriptions of the two latter localities, and analyses of the sandstones, see Geology of Wisconsin, Vol. III, pp. 202–203. Also, for figures of thin sections, Plate XIX A of the same volume. The figures of this plate, though not very successful, still serve well to mark the difference between the Keweenawan and later sandstones.

different from the more northern rocks of Keweenaw Point. The supposed structural difference between the Bohemian Range and the rest of the point seems to have been suggested partly by the unusual occurrences above alluded to, but largely also by the rounded contours of the range, the latter being taken to indicate an unbedded structure. These rounded contours, however, as one may very quickly learn from the exposures north of Lac la Belle and along the shores of Bête Grise Bay, are plainly due to the very high northern dip which here obtains, the step-like contours of the more northern ranges resulting in turn from a relatively low dip. The Bohemian Range beds, then, form the lowest part of the alternating series of lava-flows and detrital rocks, and are by no means the product of subsequent intrusion. They cannot, therefore, have produced the northward inclination.[1]

It also results that these supposed Bohemian Range intrusions did not produce the southward inclinations in the Eastern Sandstone on the southern contact; a conclusion which is sufficiently indicated by other and independent considerations. In the first place the southerly dips in the Eastern Sandstone are not restricted to that portion of the contact along which the supposed intrusions are indicated by Messrs. Foster and Whitney as having taken place. Quite beyond the western extremity of the Bohemian Range occur the most notable instances of the upturning of the layers of the Eastern Sandstone, as indicated in our foregoing descriptions of the Wall and Saint Louis ravines. Again, the south-dipping Eastern Sandstone along the north shore of Bête Grise Bay is crowded with sharply angular and often large-sized fragments of the Bohemian Range rocks themselves. The angularity and frequent softness of these fragments render it certain that they lie in the immediate vicinity of the rocks from which they were derived, a view which is abundantly confirmed by the lithological identity between the fragments and the trappean rocks against which the sandstones holding them immediately rest.

In declining to accept the existence of the supposed late intrusions of the Bohemian Range, we of course reject also another of their supposed effects, viz, the production, from the sandstone invaded, of such felsitic rocks as that of Mount Houghton. We cannot here take the space to discuss the nature of these so-called jaspers. That they are eruptive felsites and quartziferous porphyries of an entirely similar nature and origin with the rocks of that class throughout the Keweenaw Series seems to us abundantly evident. One of us has already discussed these rocks at some length in another connection.[2] We need merely point out here that they have unquestionably produced the principal part of the pebbles of the conglomerates of the Keweenaw

[1] For a fuller discussion of the structure of the Bohemian Range, see Monographs United States Geological Survey, Vol. V, pp. 179-186.

[2] Monographs United States Geological Survey, Vol. V, pp. 30-32, 95-125.

Series which, on Messrs. Foster and Whitney's view, antedate the massive intrusions by which the rocks furnishing the pebbles were produced. In the same connection we may also point out, as has already been done elsewhere at some length, the quite erroneous views that Messrs. Foster and Whitney appear to have had of the nature of the conglomerates of the Keweenaw Series, which, it appears to us, are very plainly made of water-worn fragments of the acid eruptives of that series itself.

With Messrs. Foster and Whitney's view as to the ejection of the material which formed the bedded eruptives of Keweenaw Point through a series of fissures, we can readily coincide, but we find no evidence that these fissures were placed along the course of the present Keweenaw Point. Had they been so it seems inconceivable that we should not meet somewhere with the dikes representing them. It seems to us preferable to attribute the eruptions to fissures lying quite to the southward of the course of the present trap range of the Keweenaw Point, where they are buried beneath a newer formation, or to the dike-filled fissures which we know to intersect the regions about the rim of the Lake Superior basin.

That an extended fault fissure exists along the south side of the trap range, as held by Foster and Whitney, we also think; but we cannot conceive that this fissure was in the main formed subsequent to the production of the Eastern Sandstone, as they seem plainly to maintain, or that it gave vent to any eruptive material.

In the production of this fissure, on Messrs. Foster and Whitney's view, it seems necessary to believe that the Eastern Sandstone was faulted away from the uppermost sandstone on the western side of Keweenaw Point. We have already shown that this view meets no confirmation when we come to compare the two sandstones with one another; but there are other very weighty objections against this conception. The faulting would demand a throw of 35,000 feet or over and an immensely great erosion. Moreover, there is very excellent reason for believing that the northward-dipping trappean beds of the so-called South Range, east of Lake Gogebic, are the lowermost members of the Keweenaw Series; and yet the Eastern Sandstone, when followed across the valley between the Main and South Trap ranges, is found to overlap these beds in an unmistakably unconformable position—a relation which it seems impossible to believe could exist were this sandstone merely the uppermost member of the trappean series. Further, the appearances along the Eastern Sandstone contact on Keweenaw Point are wholly against any such view. That there has been motion along this contact seems plain to us, but it certainly seems equally plain that there has been no great faulting here since the sandstone was laid down. Were this contact a fault contact only, the sandstone would not be crowded with fragments, often angular, of the rocks against which it rests.

THE AGASSIZ VIEW.

Alexander Agassiz. (In a paper On the Position of the Southern Slope of a Portion of Keweenaw Point, Lake Superior. Proceedings Boston Society of Natural History, 1868, Vol. XI). "Foster and Whitney, in their report of the Lake Superior mineral district, represent the sandstone on the south side of the trap range of Keweenaw Point as dipping south and resting conformably upon the beds of trap of the north side of the anticlinal axis of Keweenaw Point. This anticlinal axis formed by the Bohemian Mountain, as asserted by Foster and Whitney, is not found further south as far as I have had occasion to examine. In two of the ravines cut through the sandstone by creeks flowing in an easterly direction from the crest of the range towards Torch River, near the head of Torch Lake, we find good exposures of the sandstone, and in two points, one of which was examined by Foster and Whitney, we find the sandstone resting unconformably upon the trap, which has still the same northern dip as further west, of about 42° (p. 244).

* * * * * * *

"On examining this sandstone more carefully we find that the strata are made up of alternating layers of sandstone of reddish or yellowish grain and of beds of loose sandstone containing boulders, some of the beds of boulders resembling what is common on sea-shores as a mixture of mud and shingle. On breaking open several of the small boulders, taken *in situ* from the beds, we find that they consist mostly of reddish trap, but frequently we come across perfectly well-waterworn boulders of greyish trap containing amygdules, identical with the trap of the copper range a short distance west from these beds of sandstone, plainly showing that the sandstone was deposited upon the shores of the ridge of trap forming Keweenaw Point, and has not been uplifted by it as is stated by Foster and Whitney. The case is totally different with the sandstone north of the range that lies conformably upon the trap, but the sandstone of the southern side of the mineral range in the vicinity of Torch Lake is plainly of a different age, lying as it does unconformably upon the former" (p. 245).

Raphael Pumpelly. (Geological Survey of Michigan, Vol. I, Part II, pp. 2–5). "At the western edge of this belt, its nearly horizontal strata abut against the steep face of a wall formed by the upturned edges of beds of the cupriferous series of melaphyr and conglomerate, which dip away from the sandstone at angles of 40° to 60°, according to geographical position. This sharply defined and often nearly vertical plane of contact, having been seen by the earlier geologists at several points along a distance of many miles, and having been found to be often occupied by a thick bed of chloritic fluccan, which was looked upon as the product of faulting motion, was considered as a dislocation.

"This idea seemed to gain corroboration in the fact that, on the western side of Keweenaw Point, sandstones bearing considerable resemblance to those of the eastern horizontal beds occur, apparently conformably overlying the cupriferous series. Both sandstones came to be considered as identical in age and as forming the upper member of the group.

"There are many circumstances which make it difficult for us to accept this conclusion. One obstacle lies in the enormous amount of dislocation required, for instance, at Portage Lake, where the strata of the cupriferous series, with an actual thickness of several miles, dip away from the supposed *longitudinal* fault at an angle of about 60°.

"Again, there are at least two patches of sandstone lying on the upturned melaphyr beds near Houghton, though it was not easy to prove that they were not brought thither by glacial action. Mr. Alexander Agassiz informed me that he has found in the horizontal sandstones near this so-called "fault," abundant pebbles of the melaphyr and conglomerate of the cupriferous series, a fact which I found abundantly confirmed on the spot.

"Sir William Logan hints at a similar doubt as to the proximate equivalence in age

of these two series of rocks. But the most decided facts were gathered by Major Brooks and myself, during a reconnoissance of the country between Bad River in Wisconsin, and the middle branch of the Ontonagon, east of Lake Gogebic, in Michigan. Our route was chiefly confined to the surface of the upper member of the Michigan Azoic, which we have provisionally considered to be the equivalent of the Huronian.

"From Penokie Gap, on Bad River, to near Lake Gogebic, a distance of nearly 60 miles, the quartzites and schists of this formation are tilted at high angles and form a belt one-fourth to one-half mile in width, bordered on the south by Laurentian gneiss and schists. On the north it is everywhere overlaid by the bedded melaphyr (containing interstratified sandstones) of the cupriferous series. These form ridges and peaks which rise 200 to 300 feet above the surface of the Huronian belt.

"These ridges, forming the 'South Mineral Range,' unite at their western end with the Mineral Range proper, which forms really through its whole length the backbone of the tongue of land known as Keweenaw Point. Between these two ranges lies the south-western part of the Silurian trough, which has been mentioned before as extending inland from Keweenaw Bay.

"Here, as there, it is filled with the horizontally stratified Silurian sandstone, forming a generally level country. For a distance of nearly 30 miles, between the Montreal River, in Town 47, and Lake Gogebic, we found the cupriferous series apparently conforming in strike and dip with the Huronian schists, and both uniformly dipping to the north at angles of 50° to 70°. But in approaching Lake Gogebic from the west, we find that erosion of Silurian or pre-Silurian age has made a deep indentation entirely across the cupriferous series and the Huronian and into the Laurentian, so that at a short distance west of the lake these rocks end in steep and high declivities, at the base of which lies the level country of the Silurian sandstone, in which is cut the basin of the lake. From this point eastward this ancient erosion had made great inroads upon the continuity of the cupriferous and older rocks before the deposition of the Silurian sandstone. The melaphyr ridges are broken into knobs or are wanting, and no Huronian was found as far as the Ontonagon River, 7 miles away, and the limit of our observations.

"On this river, in the center of the north-west quarter of Sec. 13, Town 46, Range 41, the Silurian sandstone was found exposed in cliffs 50 to 60 feet high. The strata are horizontal or at most have a barely perceptible tendency to a northerly dip. About 150 steps from the base of this cliff there are outcrops of Laurentian schists whose bedding trends north-east towards the cliff of horizontal sandstone and dips 45° to 60° southeast. The nearest observed outcrop of the cupriferous series is in the southeast corner of Sec. 5, about four miles distant. It is a characteristic amygdaloidal melaphyr, whose bedding planes strike nearly east and west and dip 50° to north. In general terms, the conclusions we are drawn to are these:

"I. The cupriferous series was formed before the tilting of the Huronian beds upon which it rests conformably, and, consequently, before the elevation of the great Azoic area, whose existence during the Potsdam period predetermined the Silurian basins of Michigan and Lake Superior.

"II. After the elevation of these rocks, and after they had assumed their essential lithological characteristics, came the deposition of the sandstone and its accompanying shales, as products of the erosion of these older rocks, and containing fossils which show them to belong to the Lower Silurian, though it is still uncertain whether they should be referred to the Potsdam, Calciferous or Chazy. The question would still seem to be an open one, whether the cupriferous series is not more nearly related in point of time to the Huronian than to the Silurian."

The principal points of the view thus enunciated by Agassiz and elaborated by Pumpelly appear to be these: (1) The south face of the trap range of Keweenaw Point is an ancient shore cliff, having been

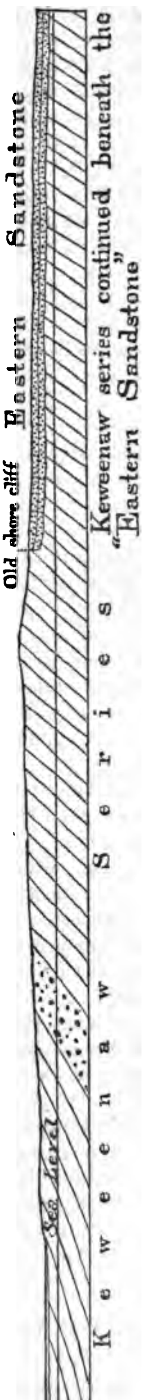

FIG. 20.—Section of Keweenaw Point, on the Agassiz view. Scale, 2 miles to the inch.

produced entirely by the erosion of the waves of that sea in which the Eastern Sandstone was laid down. (2) The Keweenaw Series extends unconformably continuously beneath the Eastern Sandstone to the South Range, the entire trough in which this sandstone lies having been produced by erosion.

To this view we have to object that it demands an almost inconceivably great thickness for the Keweenaw Series and an enormously great erosion prior to the deposition of the sandstone. By supposing the south face of the trap range to have been in the first place the result of faulting, we remove both of these difficulties, and are then able to accept the view of these gentlemen without further reserve, though with some addition.

THE ROMINGER VIEW.

C. Rominger. (Geological Survey of Michigan, Vol. I, Part III, 1873.) "The sandstones lining the eastern shore of Keweenaw Point extend approximating to the center of the Peninsula, retaining their horizontal position and also their lithological characters to such a degree that the different strata can be parallelized without difficulty with those of the more eastern localities. Near the center, the horizontal sandstone ledges are found at once abutting against the uplifted edges of a different rock series—the *Copper-bearing rocks*—which form the most elevated central crest of the Peninsula. The strike of this upheaved rock series is in conformity with the shape of the peninsula, from southwest to northeast. The abrupt edges of the strata look to the southeast and their dip is in the opposite direction, under angles variable from 40 to 70 degrees. Without intending to enter into a closer examination of the structure and composition of the copper-bearing series, I describe it in general terms as composed of mighty conglomerate beds, connected with sandstone ledges, exhibiting perfectly plain ripple-marks, which demonstrate their aqueous sedimentary origin, alternating in often-repeated sequence with powerful seams of crystalline or semi-crystalline rocks, which are comprehended under the collective name of trap but are of a very variable character and composition. The thickness of this formation is very considerable, and I think is rather under-estimated at 10,000 feet. The inconformable abutment of the Lake Superior sandstones against the Trappean series is in several places near Houghton plainly to be observed (pp. 95–96).

* * * * * *

"On the west side of the Trap range, half a mile south of Portage canal entry, large outcrops of only slightly inclined sandstone strata border the lake shore, and continue southwestward as far as the eye can reach. Along the space of about a mile, 200 feet of strata come to the surface. The uppermost are thin-bedded argillaceo-arenaceous layers; below these follow light colored sand rocks in thick ledge, which are quarried for the pur-

pose of filling the cribs built out into the lake for protection of the entry; under them again more shaly and thin-bedded layers follow; and the lowest exposed beds are dark, fine grained, hard sandstones, of laminated structure, in beds of five and six feet thickness, which are susceptible of being split into thin, even slabs of any desired thickness. This rock is also used for the above mentioned purpose, but could be quarried in large, fine blocks, which would serve a better purpose. The strata are very frequently ripple-marked and exhibit discordant stratification.

"The white and red banded or spotted appearance, so common in the series of the east side, is also observed here, and the geological horizon of these layers cannot be far below the eastern deposits. For the distance of ten or twelve miles eastward from there all the surface rock is sandstone, but the forest covering of the country does not allow us to follow across the series. A few miles west of Houghton, about a mile west of the South Pewabic stamp mills, dark, blackish brown sandstones, of fine grain, intermingled with micaceous scales, and quite hard, compose the hills. Their dip is about 35 degrees to the northwest, and a succession of such layers continues as we go eastward to the South Pewabic stamp mills, where apparently lower strata having the same strike and dip are largely exposed.

"They are in beds of various thickness and alternate with sandy shales full of ripple-marks. Next below follow conglomerate beds, some of which are composed of granules not larger than mustard seed up to the size of a pea; they have a very abundant zeolithic cement (Laumonite).

"Other conglomerate beds are very coarse, with pebbles, some of which are bigger than a man's fist. The pebbles are of porphyritic character and a good proportion of trappean rocks and pieces of sandstone and shale are intermingled.

"Laumonite and calcspar crystals likewise make part of the conglomerates, which immediately rest on crystalline trap rock. All these beds, which must amount to several thousand feet, are in conformable superposition; and the suggestion, which, however, is not perfectly demonstrated, is, that such strata, with gradually decreasing dip, succeed in a westerly direction, and connect in uninterrupted conformable series with the sandstones forming the western shore line.

The rock character of all the sandstones of the west side of the Trap range is throughout of much darker ferruginous tint and mixed with a greater proportion of cementing substance than the rocks of the east side. The red zeolithic mineral exclusively forming the cement of the finer-grained conglomerates at the South Pewabic stamp mills is also, in the much higher beds near Portage canal entry, distinctly recognizable as an admixture to the sandstones. These upper beds of the west side seem to be lower than any stratum of the east side, but from their almost horizontal position it seems highly probable that they follow the strata in conformable succession; and as the beds near the South Pewabic stamp mills, which undoubtedly make part of the copper-bearing series, seem to be their conformable continuation in the descending order, an uninterrupted serial connection between the trappean copper-bearing deposits and the Lake Superior sandstones is obvious. The discordance of the strata on the east side of the axis of elevation and their conformability on the sloping west side finds its explanation in the hypothesis of a gradual submarine upheaval of the Trap range, in its subsequent rupture, and the final emergence of the western margin from the water, while the eastern portion of the fissured earth's crust remains submerged. The deposits, which on the west side continued to accumulate with undisturbed regularity on the gradually diminishing slope, had to meet with the abrupt edges facing the east side in discordant horizontal position; and if we further suggest a following subsidence of this eastern portion, we can explain why, so close to the Trap range, on the east side of it, none of the lower beds of the series are found superimposed on the Huronian slates. These were submerged at the time that the later horizontal strata were forming (pp. 96–98)."

Summarized, Dr. Rominger's argument appears somewhat as follows: The sandstones on the lake shore at the mouth of the Portage canal

approach the Eastern Sandstone in character so closely that they may be considered as belonging to the same formation, or rather immediately below that portion of the Eastern Sandstone now exposed to view. The Portage canal sandstones *seem* to be the uppermost member of the copper-bearing series, and therefore in them we find beds linking the Eastern Sandstone and the Keweenaw Series; and the latter sandstone must therefore have conformably and horizontally beneath it, the same great trappean series that forms the greater part of Keweenaw Point. The latter series is separated from its equivalent beneath the Eastern Sandstone by a fault, but this fault took place before the deposition of the Eastern Sandstone was completed. Therefore, in being laid down, this sandstone had to meet the trappean beds unconformably on the east side of the range while following them conformably on the west side. On this view, the copper-bearing series is an older formation than the Eastern Sandstone, but is not separated from it by a great unconformity.

Dr. Rominger's conclusions rest largely upon a similarity between the sandstones at the mouth of the Portage Canal and those east of the trap range. We have already shown that this similarity is not nearly so great as has been supposed, and, moreover, that it is not evident that the Portage canal sandstones really belong to the Keweenaw Series, there being between them and the Keweenawan rocks a wide belt without exposures. We have also shown that the uppermost undoubted Keweenawan sandstones always contrast strongly in lithological characters with the Eastern Sandstone itself.

However, we find more cogent reasons for dissent from Rominger's view outside of the special field to which this discussion is limited. In the Saint Croix region we have found the Potsdam Sandstone deposited upon the upturned Keweenaw Series, and inserted in deep valleys and wrapping around considerable hills carved from the Keweenawan rocks in the interval between their upheaval and the deposition of the Potsdam Sandstone. So, also, in the Gogebic region, sandstone is found to lie horizontally in gaps eroded in the upturned Keweenaw Series. So, again, north of the Montreal, the horizontal sandstone is seen to approach within two miles of the upturned Keweenaw Series, which there stands at an angle of 80°. Manifestly, therefore, this upheaval must have taken place before the deposition of the horizontal sandstone on its two sides, and there must have been sufficient interval for the erosion of the upturned series to the depth and extent of the valleys filled by the sandstone. These we regard as specific evidences that the deposition of the horizontal series was separated from the upheaval of the tilted series by a geologically important time-interval.

Again, on Dr. Rominger's view the Eastern Sandstone must have the series of Keweenawan traps conformably beneath it; but, as Pumpelly long since showed, the Eastern Sandstone overlies the Keweenawan traps of the South Range with a most unmistakable unconformity, lying horizontally quite across the steeply inclined Keweenawan belts.

THE CREDNER VIEW.

H. Credner. (Elemente der Geologie, 1878, p. 416). "Hohes Interesse besitzen die Eruptivgesteine, welche zwischen den wahrscheinlich untersilurischen Sandsteinen am Südufer des Lake Superior in Nord Amerika eingelagert sind. Sie treten

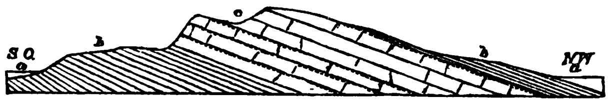

FIG. 21. Profil durch Keweenaw Point im Lake Superior (*H. Crd.*). *a* Lake Superior; *b* Untersilurische Sandsteine und Conglomerate; *c* Melaphyrlager, wechsellagernd mit Mandelsteinen und Conglomeraten.[1]

in Gestalt einer Schichtenreihe von abwechselnden Dioriten, Melaphyren und Melaphyrmandelsteinen mit untergeordneten Conglomeratbänken zwischen versteinerungsleeren Sandsteinen und Conglomeraten auf, so dass ihre Eruption und die Bildung des benachbarten Nebengesteines augenscheinlich in dieselbe Periode fällt."[2]

M. E. Wadsworth. (Notes on the Geology of the Iron and Copper Districts of Lake Superior. Bulletin of the Museum of Comparative Zoölogy, Vol. VII, No. I, 1880). "The general geological structure of the region visited by us is, then, in general, as follows. Beginning on the southeastern side of Keweenaw Point we find a sandstone and conglomerate overlaid by melaphyr. This melaphyr is again overlaid by sandstones and conglomerates, principally the latter. The alternations of melaphyr, diabase, sandstone, and conglomerate, with the melaphyr and diabase largely predominating, continue across the center of the Point, forming its backbone. As the northwestern side is approached, the sandstones and conglomerates increase, while the melaphyr and diabase diminish, until a purely sandstone formation is reached.

"All these rocks taken together make one geological formation and have been laid down successively one upon the other in order, going from the east towards the west. These rocks are known to form the same series by their conformably overlying one another. These traps are old lava flows, spread out over the then existing surface along a shore line. They have flowed the same as modern basaltic lavas do under like conditions and retain the same characters, except so far as they have been modified by the agencies to which they have been subjected since their outflow (p. 127).

* * * * * * *

"Most of these old basalts are directly covered by succeeding flows, following after greater or lesser intervals of time; but part, as remarked above, are covered by conglomerates and sandstones. These conglomerates and sandstones show, by the rounded and water-worn character of their constituent pebbles and grains, that they are beach deposits. The surface of the underlying basalt is smoothed as by water action. The overlying conglomerate is made up at its base of basaltic mud and pebbles, derived from the underlying rock and mixed with the felsitic mud and pebbles of which the conglomerates are chiefly composed. The trappean mud and pebbles diminish, or are entirely wanting, as we recede from the underlying trap (p. 128)."

[1] FIG. 21.— Section through Keweenaw Point, on Lake Superior. (H. Credner). *a*, Lake Superior; *b*, Lower Silurian sandstones and conglomerates; *c*, layer of melaphyrs, alternating with amygdaloids and conglomerates.

[2] "Considerable interest attaches to the eruptive rocks lying between the sandstones on the southern shore of Lake Superior, in North America, which probably belong to the lower Silurian. They appear as a series of layers of alternating diorites, melaphyrs and melaphyr-amygdaloids, with subordinate banks of conglomerate, between sandstones and conglomerates destitute of fossils. Thus the protrusion of the eruptive rocks and the formation of the neighboring layers evidently fall within the same period."

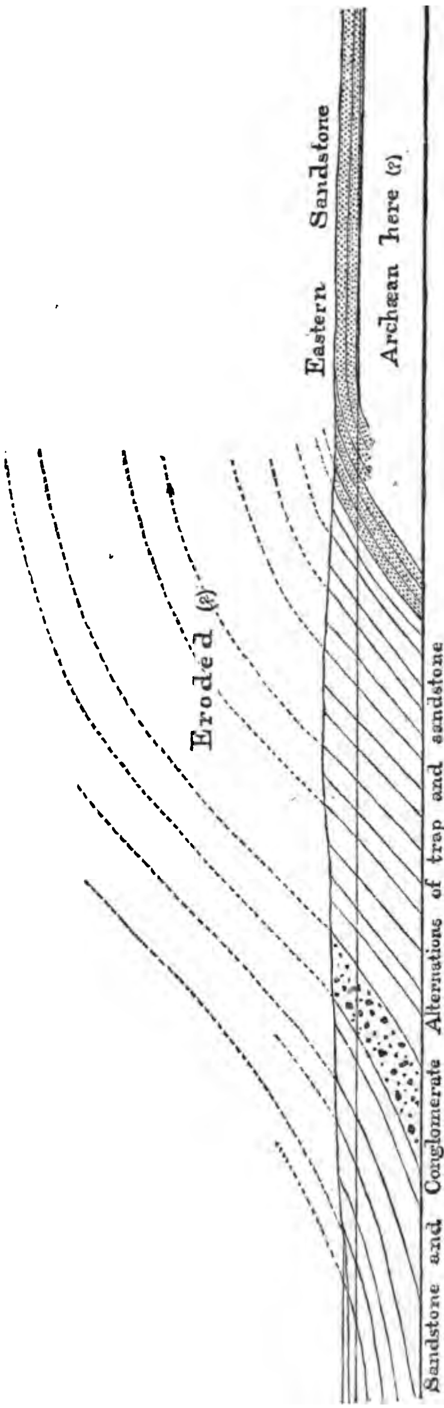

FIG. 22.—Section of Keweenaw Point, on the Credner view. Drawn to a natural scale of 2 miles to the inch.

In advancing this view Credner, as above quoted, gives only a general statement without accompanying proof, nor have we met with any paper by this author in which such proof is adduced.

In Figure 22 we give a cross-section of Keweenaw Point on the view expressed in Credner's sketch (Figure 21). Unlike his figure, we have drawn ours to a natural scale and with due regard to the inclinations of the Keweenawan beds as now determined.

Mr. Wadsworth, in advancing the same view subsequently, appealed for support only to the occurrences at the contacts on the Hungarian and Douglass Houghton Ravines. It does not appear that he advocates all of the conditions that Credner's sketch would imply, but he does not give any sketch illustrative of his views as to the general relations of the Keweenaw Series and the Eastern Sandstone. Nor does he give any sufficiently definite statements from which we can construct a sketch with any certainty that it would express his views. Indeed, we have failed, after many attempts, to reach any definite conception of a structure which would be in accordance with all of his statements.

On the structural view expressed in Credner's sketch it seems to us that it would be necessary to believe in an incredibly great amount of de-

nudation, as we have indicated in Figure 22, and in a denudation which has removed from the flat region to the south of Keweenaw Point the continuation in that direction of the trappean series. That on this view such a continuation must have existed is evident to us. It does not seem possible to conceive that the beds of the trappean series, often inclined, for enormous thicknesses, at an angle of over 45° and even up to 90° (Montreal River), with their conformably overlying enormously thick sandstone, could have been deposited in any such positions as they now occupy. They have evidently been subjected during and since accumulation to some disturbing force by which their inclined position has been produced. Except for the moderate inclinations due to a gradual sinking of the center of the basin during the growth of the series, as we subsequently explain, we conceive that the entire series must have been spread out in a relatively flat position. That this was so seems sufficiently evident from the interleaving throughout the series of water-deposited, often ripple-marked, sediments. Even at the very summit of the series, in the region of the Montreal River, the ripple-marked sandstones stand now at an angle of 80° to 90°. On the river named, indeed, the entire Keweenaw Series, with a thickness of over 45,000 feet from the lowest trap to the highest sandstone, occupies a vertical position; while but a few miles away the Eastern Sandstone lies horizontally.[1] It seems manifest, then, that if the latter sandstone be the basal member of this series, the entire 45,000 feet or more of sandstones, conglomerates, and traps must once have been spread out horizontally on top of it. Reconstructing the conditions that must have obtained at this time and before these rocks were thrown into an inclined position, we find ourselves forced to one of two alternatives: either this great thickness stopped suddenly to the south with a vertical wall of this height or else it once extended far to the southward of the present northern limit of the Eastern Sandstone. Of these alternatives we must, of course, select the latter; when we immediately find ourselves obliged to explain the entire absence of outliers of this great series in the sandstone country to the south. In other words, this theory offers no satisfactory explanation for the singularly abrupt, linear, often cliffy, southern limit of the trappean series. With Jackson, the southern face of the main trap range is the result of intrusive eruptions along its line. With Foster and Whitney, and with Rominger, it is the result of faulting. With Agassiz and Pumpelly, it is a cliff of erosion, but erosion before the deposition of the Eastern Sandstone. The view at present under discussion offers no explanation for this abrupt limit, but it is evident that under this view also we must regard it as a cliff of erosion. But an erosion that leaves a linear cliff without recesses or outliers, and one which yet has in front of it unharmed a soft and friable sandstone, above which once lay a continuation of the rocks composing the cliff, is to us quite incredible.

[1] Monographs United States Geological Survey, Vol. V, pp. 226–230, Plates XXI, XXII.

There are many other considerations of a general character which forbid an acceptance of the Credner hypothesis. We may merely refer to the singular difficulty this view offers us in interposing between the Eastern Sandstone and the overlying Calciferous, the great trappean series of over 45,000 feet thickness, of which over a third is sediment; and this when but a few miles away from Keweenaw Point, eastward from Marquette, the Eastern Sandstone grades upwards imperceptibly into the Calciferous. Still nearer to the south face of the Keweenaw Range is the Trenton Limestone of the hills in Sections 13, 14, 23, and 24 of T. 51, R. 35 W., as described by Rominger and others. Experience with the lower Paleozoic throughout the Northwest would warrant us in believing that underneath these limestones, and between them and the still lower Eastern or Potsdam Sandstone, lies the Calciferous, now hidden by drift. But even if this be not the case, and the Trenton here be placed directly on the Potsdam, it is a heavy strain on our credulity to ask us to place the great Keweenaw Series in this interval.

Turning now our attention to the occurrences along the immediate contact line between the Eastern Sandstone and the trappean series, upon which occurrences at two localities Mr. Wadsworth bases his advocacy of a view essentially the same as that of Credner, we observe that he makes special use of (1) a passage of the Eastern Sandstone conformably beneath the trappean series, (2) an interstratification of the Eastern Sandstone with traps at the junction, (3) an induration of the Eastern Sandstone at the junction by the heat of the overlying trap, and (4) the absence of fragments derived from the trappean series within the Eastern Sandstone below the contact. We have already, in describing the several important localities, shown that the facts, as we read them, do not support Mr. Wadsworth in any of these points.

We need not repeat details here, but as to the conformable passage of the Eastern Sandstone beneath the trappean series may recall that, on Bête Grise Bay, three localities have been described by several different observers, by all of whom it is specifically asserted that the Eastern Sandstone does not pass beneath the Keweenaw Series at all, but overlies it; that in the Wall Ravine, the Eastern Sandstone, instead of dipping beneath the Keweenawan beds, as demanded by this hypothesis, shoots upward toward the zenith; that in the Saint Louis Ravine the beds are likewise turned skyward near the contact and at a short distance away they dip at lower inclinations *away* from the Keweenaw Series; that Pumpelly and Rominger describe the Eastern Sandstone near Houghton as dipping away from the Keweenaw Series at a notably high angle; that in the region back from Ontonagon Chauvenet describes the Eastern Sandstone as likewise dipping away from the Keweenaw Series near the contact; and that in none of these localities is there any approach to a conformity with the hypothesis of Credner and Wadsworth. We may also remind the reader that there *is no such conformity* at the specific localities from which Mr. Wads-

worth draws his sole support of the theory. If the Eastern Sandstone is a lower and conformable member of the Keweenaw Series, and has merely been brought to the surface by denudation, it should be found to present a dip and a general stratigraphical behavior harmonious with the rest of the great series. Now, the Keweenaw Series possesses a quite remarkable steadiness and uniformity of dip in this district. It is nowhere notably warped, nor does it abruptly change from one stratigraphical aspect to another. The careful studies of Pumpelly and Marvine, the actual subterranean explorations of the numerous mines of the peninsula (reaching down, in two instances, to more than 3,000 feet), and the assiduity with which every portion of it has been prospected, have furnished us an unsurpassed demonstration of its thoroughly bedded condition and of its stratal uniformity and consistency. In the immediate vicinity of the localities which have been appealed to in support of this view, the great Calumet and Hecla mine has followed down the slope of a thin bed of conglomerate more than 3,500 feet. The engineers of the mining company have determined the dip with the greatest precision, and found it to be so steady and uniform that so precise a dip as 38½° has been adopted as a working basis, and variations from this angle are found so slight that it is more economical to cut them down to the adopted uniform plane than to adjust the workings to the slight inequalities of the dip. The experience in other mines and the remarkable profile sections of Marvine testify to the same striking feature. Now, it is simply incredible that just along the line at which the superior beds happen to be denuded away from over the supposed underlying sandstone, there should happen to be the various distortions of the strata above described, and that there should be a sudden transition in the general character of the dip and the stratigraphical behavior of the series. It is the more surprising since, a little away from that line, the dip again becomes measurably uniform. If this view were true, the dip of the Eastern Sandstone should be essentially the same as that of the Keweenaw Series, or if there were a flattening to the eastward it should be gradual and progressive to be in harmony with the rest of the formation. Now, in the Douglass Houghton Ravine the beds of the Eastern Sandstone, instead of passing conformably beneath the trappean series with a like steady dip, are warped and angulated in a manner altogether inconsistent with the character of the Keweenaw Series. In the Hungarian Ravine the dips of the Eastern Sandstone are similarly discordant with those of the Keweenaw Series, and such an abrupt change in the general character of the dips as that which occurs at the junction is nowhere known in the undoubted Keweenaw Series of this district. There is an entire incongruity between the stratigraphical characteristics of the Eastern Sandstone in these ravines and the adjacent Keweenaw Series. Were it not for this conspicuous incongruity, and were it not for the fatal evidence at several other points, the fact that in the Hungarian Ravine, and in part in the Douglass

Houghton Ravine, the beds of the Eastern Sandstone at the immediate contact are bent downward in approximate conformity to the overhanging Keweenaw beds might afford some apparent support for the hypothesis. But this is so manifestly one of the several phases of the distortion that accompanies the contact of these diverse formations that we do not see how any weight could be attached to it, even if the nature of the junction and the other classes of evidence did not stand so completely in antagonism to it. So far as we can see, there is no single instance along the whole line which conforms, even approximately, to a consistency of dip between the Eastern Sandstone and the immediately adjacent portion of the Keweenaw Series. In other words, we hold the theory to be entirely without stratigraphical support.

The interstratifications of the Eastern Sandstone and traps in the Douglass Houghton Ravine we do not accept, for reasons already given at some length.

As to the induration of the Eastern Sandstone by the heat of trappean overflow at the junction, we have to say that we find no greater induration at the contact than at points distant from it; besides which, it is to be remarked that even were such induration present it would, in our view, be no proof of heat action, unless it were proved to be baking, as of argillaceous materials, or semi-fusion.

With regard to the absence of pebbles from the trappean series in the Eastern Sandstone below the contact, we would say that we find such pebbles in the greatest abundance and *no others*. These pebbles are from both the acid and basic eruptives of the Keweenaw Series. Mr. Wadsworth recognizes the presence of the acid pebbles, describing a number, and showing that they are identical with the acid pebbles of the conglomerates of the trappean series itself. His denial of the occurrence in the Eastern Sandstone of fragments from the supposed Keweenaw Series is based upon a lack of fragments from the ordinary basic eruptives of that series. It seems evident that when he wrote he did not regard the acid pebbles as of Keweenawan derivation. Yet the rocks represented by these pebbles occur abundantly in the Keweenaw Series, and especially in the lower horizons of that series nearest to the contact line; and there is no other group of rocks known to exist in the entire Lake Superior region from which these pebbles could possibly have been derived naturally in the variety and assortment in which they exist. Moreover, pebbles of the basic Keweenawan eruptives, whose presence in the Eastern Sandstone is denied by Wadsworth, are to be found there in the greatest abundance, and often of a character not merely in a general way corresponding to that of the Keweenawan basic rocks, but of kinds corresponding in every detail with individual rocks *in situ* at the immediate contact. Again, as these pebbles range from three to five hundred feet below the uppermost beds of the Eastern Sandstone, we see no tenable explanation of their occurrence under Wadsworth's hypothesis. Furthermore, the distribution and the spe-

cial character of these pebble seems to us to quite clearly indicate their local derivation from an immediately adjacent shore.

In addition to the foregoing considerations we may urge that if the Eastern Sandstone is a lower conformable member of the Keweenaw Series, the contact between the two should assume one of the usual depositional forms. In this instance the sandstone is supposed to have been overflowed by a flood of lava and should present the characteristics of such a succession. This Mr. Wadsworth assumes, and asserts that the underlying sandstone was baked by the igneous overflow. But we have shown, by extensive excavations in the Hungarian, Douglass Houghton and Wall Ravines, and on Bête Grise Bay, that at the contact there lies a bed of mixed trappean fragments, comminuted trap, joint clay, and quartzose sand, all of which remain soft and do not present the slightest evidence of baking due to the supposed overflow. Furthermore, we have found the basal portion of the igneous rock to present a poorly defined surface instead of the definite amygdaloidal base which the lava flows of the region usually present. So, in like manner, we have found the adjacent surface of the Eastern Sandstone also incomplete, instead of presenting the determinate surface which it should have possessed when overspread by the lava. In short, with the exception of the problematical rock in the Hungarian Ravine, which we have described above, we find nowhere the slightest evidence of the igneous overflow which Mr. Wadsworth advocates; but, on the contrary, we find specific evidence which we conceive to be altogether fatal to it.

There is an additional and grave objection to this view. If the Eastern Sandstone is a conformable lower member, its uppermost bed should be the one always in contact and it should underlie the basal member of the trappean series. But at no two localities, within our observation, have we found the same beds in contact. At the eastern Bête Grise Bay locality (B of Plate II) the sandstone joins an ordinary diabase of the Keweenaw Series. At the western locality (A of Plate II) the sandstone rests upon a luster-mottled melaphyr. Both of these we place low in the series. In the Wall Ravine the sandstone stands next to porphyritic conglomerate much higher in the series. In the Saint Louis Ravine it adjoins a diabase which lies but a short distance below the Saint Louis conglomerate. In the Douglass Houghton gorge, it comes in contact with a decomposed diabase occupying a different horizon, while at the Hungarian locality it touches a diabase which immediately underlies a thick, coarse conglomerate. Now, when it is considered that the last four localities are immediately adjacent to each other, the whole four lying within a space of six miles, it is doing great violence to the known character of the Keweenaw Series to suppose that these differences of contact are due to replacements in its basal beds. For, whatever may be theoretically held concerning the persistency of the lava flows, the beds of conglomerate cannot be hypothet-

ically produced and dismissed with such license. But, in fact, it is quite at variance with the ascertained character of the Keweenaw Series to suppose that either the igneous or detrital beds enter and disappear with the suddenness which this view assumes.

On the other hand, the member of the Eastern Sandstone which makes the contact does not appear to be the same in the several instances. At the eastern locality, on Bête Grise Bay, a conglomerate lies next to the diabase. At the western locality, the contact member is the peculiar shale breccia above described. In the Wall Ravine, the junction member is a sandstone some distance below the most conglomeratic beds. In the Saint Louis Ravine, the contact is formed by sandstone and conglomerate lying close below the most conglomeratic beds. In the Douglass Houghton Ravine, the junction beds are sandstone and shales above the most conglomeratic beds; while in the Hungarian Ravine the junction is made with a thick sandstone stratum which appears to lie some distance above the most conglomeratic beds. On the view which we hold, that these sandstones, shales and conglomerates were formed along a shore line at the base of the Keweenawan escarpment, it is not improbable that frequent minor changes of character occur in the beds as traced along the shore, and we do not, at present, feel prepared to assert that the conglomeratic beds in the several sections are necessarily the same; yet, even under our view, we believe that they are essentially identical, at least so far as the coarse "mud and shingle" deposits of the last four adjacent localities are concerned. But under the hypothesis that these are members of the Eastern Sandstone of distant derivation, a much greater uniformity must be postulated, for they are not within twenty miles of any supposable shore line. It seems to us, therefore, altogether incredible that, under that hypothesis, contacts should occur which were never the same at any two localities, even though they are only one or two miles apart.

It appears to us, therefore, that the view is fatally defective in not coinciding with the facts at the contact line.

Several additional objections lie against this view, but we do not deem it needful to urge them in the wake of these that seem to us so conclusively fatal.

OUR OWN CONCLUSIONS.

Our own previous expressions of opinion regarding the phenomena observed along the south face of the Keweenaw Range are contained in the following quotations:

T. C. Chamberlin. (In Geology of Wisconsin, Vol. I, Part I, 1883, pp. 105–106): "Parallel to the southwestern projection of Lake Superior, in Douglas and Bayfield Counties, there runs a cliff formed by the upturned edges of igneous southward-dipping beds, against which a later formed horizontal sandstone (Potsdam) abuts, show-

ing that it stood as a sea-cliff in the Potsdam seas. Keweenaw Point presents a similar phenomenon of more striking character, its beds dipping northwestward and exposing in the opposite direction a mural face against which abuts a similar horizontal sandstone. This may all possibly be the work of erosion in the great interval otherwise demonstrated to exist between the Keweenawan period and the Potsdam, but the extent and the regularity of the cliff-faces lends support to the hypothesis that the phenomenon is due to displacement, afterwards modified by erosion. If these cliffs were produced by faulting, the displacement was doubtless attended by the nearest approach to a great convulsion that the period witnessed. At best, this might amount to the settling down of a small bit of the globe's crust to a depth perhaps one ten-thousandth part of its distance from the earth's center—a local phenomenon of great importance, to be sure, but relative to the whole globe, only trivial."

R. D. Irving. (In Copper-Bearing Rocks of Lake Superior, Monographs United States Geological Survey, Vol. V, 1883). "It seems to me that the south face of the Keweenaw Range is both a fault cliff and a shore cliff, against which the newer Eastern Sandstone was laid down, but not until after a large erosion; and that faulting took place again after or else continued until after the deposition of the sandstone. The original faulting seems to be demanded on this line by the general structural relations of the Keweenaw and South ranges, as shown on a previous page, and by the absence of outliers of the immense thickness of rocks of the Keweenaw Range to the southward. That the Eastern Sandstone was deposited subsequently to this first faulting is evidenced by its containing conglomerate layers in which the pebbles are frequently of Keweenawan eruptives, basic as well as acid (Bête Grise Bay), and by the way in which it cuts across the course of the South Range beds. That faulting motion took place along the fault line after or during the deposition of the Eastern Sandstone is indicated by the way in which the sandstone dips southward along the junction at the south side of the Keweenaw Range (p. 365)."

"The relation of the rocks of the South Range to those of the Keweenaw Point Range is one of the greatest interest. A moment's inspection of the map of Plate I will serve to show that towards the east the two ranges are widely separated, the distance between them, even west of the Ontonagon, being as much as 18 miles, while still further west they rapidly approach, and finally join. The beds of both ranges dip northward. Should we suppose a continuous series beneath the intervening horizontal sandstone, we should obtain an incredible thickness, and one which westward must diminish with an incredible rapidity, for after the two ranges have joined the total apparent thickness of the Lower Division of the series does not exceed 33,000 feet, or only 8,000 feet more than on Keweenaw Point. That there is a fold beneath the sandstone-filled area seems improbable. There is no sign of a southern dip along the south side of the Keweenaw Range during all its course from Bête Grise Bay to its junction with the South range. I had at one time the idea that such a fold might exist, Foster and Whitney in their report indicating the existence of a southern dip along the south side of the Keweenaw Range, but I have since convinced myself by examination that no southern dip exists.

"To explain the sudden break on the south side of the Keweenaw Range between the Keweenawan beds and the Eastern Sandstone, Foster and Whitney long since supposed this line to be one of fault and the Eastern Sandstone to be the equivalent of that on the west side of the range, the two separated only by the faulting. The latter position I shall show subsequently to be untenable; and yet that some faulting has taken place on this line, even after the deposition of the sandstone, is proven plainly enough by the fact that at the contact the sandstones commonly rise in a remarkable manner, presenting for short distances from the junction high southern dips. On Bête Grise Bay these dips reach 50° at the contact, lessening to 40° and 30° within 200 feet and to horizontality within a mile or less. Farther west the dips at

the contact lessen in amount, becoming scarcely perceptible at Portage Lake, beyond which to the west they again become high. These phenomena are beautifully displayed at a number of points along the west branch of the Ontonagon, east of Lake Agogebic.

"These facts render it plain enough that some faulting took place on this line after the deposition of the sandstone, but the main faulting, I conceive, took place before. By this fault the Keweenaw Range escarpment and the valley south of it were first made, the width of the valley depending on the amount of throw of the fault, which was thus greatest to the eastward. Subsequently, the newer sandstone was deposited in this valley, and, after its deposition, a comparatively insignificant amount of faulting took place on the same line. On this view the South Range beds are the basal beds of the series, while the underlying basement of the intermediate sandstone-filled valley is composed, in a measure, of the same beds as those forming the Keweenaw Range (pp. 203–205)."

Preliminary to a renewed and fuller presentation of our conclusions we desire briefly but distinctly to set forth (1) certain prime characteristics of the formations under consideration with which any tenable view must be in harmony; and (2) certain specific conditions which an adequate hypothesis must satisfy.

The bedded nature of the Keweenaw Series.—Among the prime characteristics it is important to reaffirm the bedded nature of the Keweenaw Series, not because it is disputed but because it needs emphasis. With the exception of the Bohemian Range, there never has been any ground for questioning the thoroughly stratified condition of the formation of the Keweenaw peninsula. That the great terrane consists of detrital beds, definitely interstratified with lava sheets, has been most thoroughly demonstrated both by geological investigation and by industrial exploitation. With the determination made by one of us that the Bohemian Range is likewise bedded, in the main, there passes away the last definite ground for regarding the Keweenawan rocks as otherwise than thoroughly stratified.[1] There is no sanction in the observed phenomena for any appeal to the assumed license of "eruptive geology" The structure of Keweenaw Point is in no proper sense eruptive. Essentially all its beds are the result of fluidal deposit. The one class, lava flows, distributed and deposited themselves by virtue of their own fluidity; the other, the clastic beds, by the borrowed fluidity of water. The products of both are alike amenable to the common laws of stratigraphy, and, for the purpose of general structural conceptions, it is quite immaterial whether the stratified condition arose from the one or the other variety of fluidal deposition. We conceive it to be a grave

[1] The Copper-Bearing Rocks of Lake Superior, Monograph V, United States Geological Survey, pp. 179–187. Through the kindness of Dr. C. Rominger, State geologist of Michigan we have been allowed to look over the MS. of his forthcoming report on the Keweenawan rocks of Michigan, and find that he has quite independently come to the same conclusion as to the bedded structure of the Bohemian range. Dr. Rominger's detailed studies have also brought out many new points with regard to this interesting part of Keweenaw Point.

error to confuse the phenomena of eruption with the phenomena of the deposition of erupted material. When a mud volcano belches forth its mixed contents the *eruption* belongs to the domain of eruptive geology, but the descent of the fluid mass down the mountain side belongs to the domain of fluvial geology; and the deposition of the mass in the valley belongs to the domain of sedimentary geology. So, when great flows of lava issue from the earth, the extravasation belongs to the sphere of eruptive geology; but the distribution of molten material in vast sheets over adjacent or perchance distant plains, results in a deposit that is amenable in every essential respect to the recognized laws of sedimentary stratigraphy. We should need to crave pardon for these elementary statements did not the history of the discussion of this region seem to render them imperative.

Whatever explanation of the structure of Keweenaw Point is adopted must, therefore, conform to simple stratigraphic laws.

The uniformity and steadiness of dip.—Not only is the Keweenaw Series thoroughly bedded, but, in the region involved in this discussion, it presents a uniformity and steadiness of dip unusual in a series so highly tilted. It is notably free from those warpings, foldings, and sudden changes of dip that are common characteristics of tilted series. In its original horizontal condition there is every reason to believe that its bedding was of very exceptional uniformity. The enormous extent of the series, as well as the structure of the beds, implies that the outpourings of lava were copious in a most extraordinary degree, and, if so, they must have spread themselves into sheets of almost absolute horizontality. The extent and persistence of the igneous, as well as of the detrital beds, strongly confirm this view. The phenomena probably find their best modern exemplification in the lava fields of Oregon, Idaho, and adjacent Territories. The following graphic sketch by Archibald Geikie fits the phenomena of the Superior basin in all structural essentials: "We rode for hours by the margin of a vast plain of basalt, stretching southward and westward as far as the eye could reach. It seemed as if the plain had been once a great lake or sea of molten rock which surged along the base of the hills, entering every valley, and leaving there a solid floor of bare black stone. We camped on this basalt plain near some springs of clear cold water which rise close to its edge. Wandering over the bare hummocks of rock, on many of which not a vestige of vegetation had yet taken root, I realized with vividness the truth of an assertion made first by Richthofen, but very generally neglected by geologists, that our modern volcanoes, such as Vesuvius or Ætna, present us with by no means the grandest type of volcanic action, but rather belong to a time of failing activity. There have been periods of tremendous volcanic energy, when, instead of escaping from a local vent, like a Vesuvian cone, the lava has found its way to the surface by innumerable fissures opened for it in the solid crust of the globe over thousands of square miles. I felt that the

structure of this and the other volcanic plains of the far West furnish the true key to the history of the basaltic plateaux of Ireland and Scotland, which had been an enigma to me for many years."[1]

The enormous thickness of the Keweenaw Series.—An acceptable view must take account of the stupendous depth of the Keweenaw Series. If the Eastern Sandstone is to be held the equivalent of the upper member of the Keweenaw Series, and has been separated from it by a downthrow, the thickness of the series is a measure of the faulting. If the measure were only moderate this hypothesis would be put to no unbearable strain, but when it is shown that the thickness of the beds reaches some such minimum measure as 35,000 feet, the burden laid upon the hypothesis is great and it staggers under its own load. Before it can stand it must be supported by the strongest direct evidence.

If, again, the Keweenaw Series is thought to be sandwiched between the upper and nether members of the Potsdam Sandstone, the thickness of the Keweenaw Series is a measure of the strain of distension put upon the Potsdam. As we know it, the Potsdam is, at most, a series of 1,000 feet in thickness. It may somewhere be thicker. But when we theoretically imbed within it 35,000 feet of strata, or any more moderate measure to which the Keweenaw Series can possibly be reduced, the strain put upon the hypothesis is unbearably severe. It bellies out the Potsdam to an inordinate extent. A boa may swallow an ox, but not an elephant.

The general horizontality of the Eastern Sandstone.—The proximity of a horizontal series to a highly dipping series of enormous thickness is a factor of which cognizance must be taken in framing an hypothesis concordant with the phenomena. It is not a fact which necessarily presents supreme difficulties, but is one which must fall into easy concordance with the true hypothesis, while it will be apt to display some incongruity with a false one.

The quartzose character of the Potsdam sands in distinction from the silicate nature of the Keweenawan sands.—Had the Eastern Sandstone been a gray shale it would probably never have been regarded as the equivalent of any portion of the Keweenaw Series, because of the differences in the conditions of derivation which such a character would imply. It is doubtful, however, whether such differences of implied condition would be really much greater than those which are now implied. The conditions which produced the silicate Keweenawan sands must have been notably different from those which gave rise to the quartzose Potsdam sands.

Mutual relations and distribution of the two series.—There must also be a due consideration of the great relations of the two series, in their mutual positions and in their distribution. The consideration of this lies mainly outside of our present province, and we will not here attempt

[1] Geological Sketches, p. 237.

its discussion, contenting ourselves with a reference to our previous publications;[1] but the subject cannot be thus lightly passed in the formation of a just and comprehensive judgment. To attempt to settle the question of the relations between two such extensive series upon anything less than all the information obtainable from all sources, is as dangerous to safe conclusions as it is illiberal in method.

Relations to topography.—Every geologist of acumen has found the teachings of topography profoundly instructive concerning both structure and past history. It lends most valuable aid in correcting false inferences and in suggesting true ones. The fact that the Keweenaw peninsula now consists of an elongated promontory, not greatly dissected by erosion nor deeply undulate or serrate in its crest line, will be esteemed by topographic students a witness of much value in weighing any hypothesis that postulates extraordinary elevation by faulting. The fact, on the other hand, that over the area of the Eastern Sandstone, 100 miles in length, there is an absence of outlying remnants, will likewise weigh in the adjudication of any hypothesis which assumes that the tract was once overlain by the great trappean series. There are other features of topography that do not admit of a brief statement, which lend more or less specific testimony to the verity, or otherwise, of the several structural hypotheses.

The relation of the two series to drainage.—The history of the district under consideration cannot be truly read without taking thought of its significant drainage features. Among these is the remarkable fact that no great stream traverses the low-lying tract of the Eastern Sandstone. It is a depressed belt of land, 100 miles in length, lower than the ridged tracts on either hand, and yet it is not the valley of any great stream. The drainage channels of this belt cross the Keweenawan ridge, and empty into the great basin. Even the glaciers that plowed along this belt did not obliterate these interesting features. The Ontonagon River and the Presque Isle river cross the sandstone plain and cut through the Keweenawan uplift. The great cut occupied by Portage Lake appears to be a similar preglacial channel. These and other transverse drainage features must find a meaning in any full reading of the history of the region.

The foregoing may be said to be general characteristics with which the true explanation must be harmonious. The following are more specific requisitions which it must directly meet:

The comparative straightness but gentle undulation of the junction line

[1] American Journal of Science, 1874, Third Series, VIII, 46–56, R. D. I.; "On the Age of the Copper-Bearing Rocks of Lake Superior, and on the Westward Continuation of the Lake Superior Synclinal," Vol. III, Geology of Wisconsin, 1880, Part I, pp. 1–25, R. D. I.; Vol. I, Geology of Wisconsin, 1883, pp. 94–118, T. C. C.; Science, Vol. I, pp. 453–455, T. C. C.; Third Annual Report United States Geological Survey, R. D. I.; Copper-Bearing Rocks of Lake Superior, Monograph V, United States Geological Survey, 1883, p. 356, *et seq.*

throughout its course of nearly one hundred miles.—If it is a fault line, directness of course is precisely what is to be expected. If it is merely an erosion cliff, formed by the cutting back of the Keweenaw Series, its directness of course and its freedom from headlands, retreating embayments and deep incisions, are quite remarkable. If it is the compound product of faulting, determining a general line of escarpment, and of erosion, subsequently working upon that, an average directness of course, with subordinate undulations, will satisfy the hypothesis.

The coincidence of the line of escarpment with the line of junction of the two series.—The term "escarpment" is a convenient one, almost indispensably so, but does not quite accurately express the facts, since the surface does not always drop suddenly down in a precipitous face, but in some districts curves smoothly, though steeply, down to the lower tract. The phenomenon is not the familiar one of a mural face set forth by the undermining of a softer stratum, and the coincidence of the brow of the trappean series with the junction line has more than a mere fortuitous significance.

Disturbance along the line of contact.—A factor of supreme moment is the distortion of strata that everywhere, so far as observed, prevails along the junction line. This is the more emphatically significant since it does not notably affect the immediately adjacent region. The Keweenawan beds on the one side are almost wholly uninfluenced, while the Eastern Sandstone, at a short distance from the junction, lies essentially as first deposited. It is further to be noted that the distortion is almost wholly suffered by the sandstone series, or what we conceive to be the later, weaker and merely superficial series, while the deep, massive Keweenawan terrane was not visibly flexed.

The special character of the distortions.—Not only must the true view take account of the fact of disturbances along the junction, but it must recognize the special character of the dislocations. The beds are bent up in the majority of instances, but in two notable cases they are bent down. There are also sudden warpings and angulations of the sandstone for which an adequate cause must be found.

Character of the junction.—There must also be a consideration of the contact relations between the Eastern Sandstone and the trappean terrane. A complete view must comprehend in its scope the overlying junctions, as at Bête Grise Bay, and the underlying contacts, as in the Douglass Houghton and Hungarian Ravines.

The junction débris.—Coming down to the immediate contact, the true view must embrace a consideration of the junction débris. Account must be taken of its partly trappean and partly detrital composition, of its foliated structure, of its slickenside markings, of its inconstant thickness and of its entire freedom from any indications of direct igneous action.

The contact faces.—The true view must also recognize the fact that *the traps at the junction* have not been found to possess definite amyg-

daloidal surfaces, such as characterize the limits of the lava flows elsewhere, but present irregular and broken faces, or give other evidences that the surfaces are not original. In like manner, the sandstone does not show completed beds or depositional terminations.

Contact of different members.—A true conclusion must furthermore take note of the fact that the Eastern Sandstone comes into contact with different members of the Keweenaw Series at different points and that these members are not alone of the igneous class, whose extent and persistency some may question, but of the detrital order. Since observation has shown that both these members have a very notable degree of persistency, we do not think that any view is satisfactory which does not explain this diversity of contact without supposing that the beds have been replaced by others. Indeed, the proximity of contacts with different members is so close as to render such an explanation quite violent.

Discordance of strike.—The true view must further take cognizance of the fact that the contact line is not precisely concordant with the strike line of the Keweenaw Series at the points of contact. The general line of junction is closely approximate to the general line of strike, but in detail there are notable deviations from it, which cannot be ignored.

The disturbed condition of the Eastern Sandstone is such as to make its lines of strike quite varying, and they are often discordant both with the line of contact and with the line of strike of the Keweenaw strata. We must deal, therefore, not only with the discordance between the strikes of the two series of strata mutually, but with the discordance between each and the common junction.

The derivation of the pebbles of the Eastern Sandstone.—The true view must give a satisfactory account of the derivation of the pebbles of the Eastern Sandstone. It must recognize that they are undoubted derivatives from the igneous members of the Keweenaw Series, and that they were taken from no single stratum, but from the various members, some acidic, some basic.

The distribution of the pebbles.—It must further recognize the observation that pebbles are abundant, and often large, in the immediate vicinity of the Keweenaw Series, but are not known at great distances from it.

The imperfect assortment of the pebbles and matrix.—It must further consider the fact that the separation of the pebbles from the much finer material is incomplete, the assortment is imperfect, the classifying process did not complete its work; it is a "mud and shingle" deposit, and not a thoroughly assorted series of sandstones, shales and conglomerates.

The angularity of the pebbles.—It must also take note of the fact that the pebbles are singularly angular in some situations and rounded in others.

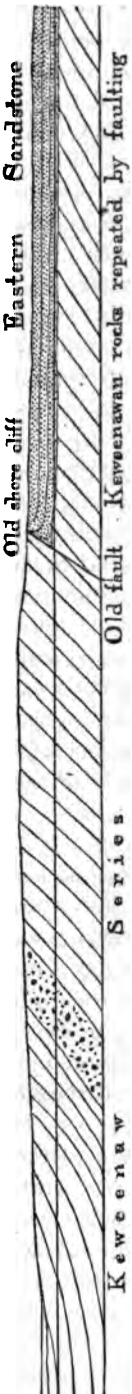

FIG. 23.—Section of Keweenaw Point, showing true relation of the Eastern Sandstone and the Keweenaw Series. Scale, 2 miles to the inch.

The absence of large fallen cliff masses.—It must account for the still further observation that while there are pebbles of trappean origin in the Eastern Sandstone, there is at the contact a general absence of great fallen cliff masses.

The proximity and relations of the Trenton Limestone.—It must also account for the fact that at no greater distance than seven miles from the upturned edge of the great Keweenaw Series, Trenton Limestone, in horizontal attitude, crowns a hill lying in the Eastern Sandstone area.

The foregoing are a full score of specifications which a true structural hypothesis must satisfy. We regard them as so significant in their character and so exacting in their demands that little latitude is permitted in the formation of our views. Taken together, they seem to us to point with great definiteness and with quite unequivocal directness to a true conception of both the genesis and the structural relations of the formations in question. Our chief conclusions are as follows: *That the Keweenaw Series is much older than the Eastern (Potsdam) Sandstone; that it was upturned, faulted along the escarpment, and much eroded before the deposition of the Eastern Sandstone; that the latter was laid down unconformably against and upon the former, and that subsequently minor faulting along the old line ensued, disturbing the contact edge of the sandstone.*

It remains to show specifically how these views meet the foregoing requirements, or, as we should prefer to phrase it, it remains to show how the foregoing requirements demand the views to which they have led us up. We will follow essentially in order the foregoing list of imperative qualifications.

In common with most students of the region, we hold that the bedded nature of the trappean series was due to a succession of immense floods of lava, which spread themselves widely over the plain of the Superior basin. Contemporaneously with this, subaqueous sedimentation was in progress, introducing, at intervals throughout the gigantic pile, clastic beds, whose character and surface markings demonstrate their horizontal deposition. Unlike some others, however, we do not conceive the Keweenaw peninsula, nor indeed the great basin generally, to have been the immediate region of important eruption. The evidence leads us to believe that the loci of eruption

lay around the rim of the basin, and not immediately in and beneath it. In the discussion of the bedded series, we, therefore, make no appeal to the assumed license of "eruptive geology." We find no evidence of more than the most trivial igneous intrusions in the region under debate. We believe its structural problems must be solved entirely apart from the phenomena of intrusion.

We conceive the uniformity and steadiness of dip which characterize the Keweenaw peninsula, and, in a somewhat similar degree, the great basin itself, to be the result of a slow and progressive settling of the basin center during the long process of deposition of the deep series. This central depression we believe to have been accompanied by an elevation of the rim in the districts of eruption. We find evidence of this in the certainty that the clastic members of the Keweenaw Series are chiefly derived from the series itself. They cannot be derived from any series now known to occupy the surrounding territory. We find further evidence of this in the fact, which generally obtains, that the lowermost beds come to the surface at higher angles than the uppermost ones. It appears that the rim of the basin was continually being eaten away by drainage erosion and contributing material to the sedimentation in progress in the settling central portion. Further than this, we conceive that the basic lavas, being the most liquid, flowed freely into the basin plain, and spread themselves widely over it, while the more viscous acid eruptions accumulated more largely in thick embossments in the districts of eruption about the margin, where they were exposed to easy degradation, and that, therefore, these furnished a larger percentage of detritus than the basic members. The hardness, brittleness and relative lightness of the acidic material were also favoring conditions.

Now, a dip formed by progressive subsidence and sedimentation, running apace, is most naturally free from great irregularities. But the total dip observed cannot have been so attained; for the uppermost beds known to belong to this series are themselves considerably tilted at most localities and at the mouth of the Montreal River are upturned at an angle of between 80° and 90°. The later movement, however, appears to have been but an extension of the earlier. It is only at a few localities, the most notable of which is the vicinity of the Porcupine Mountains, that anything approximating abrupt warpings have been observed. Into the later movement of the strata there may have entered something of the lateral thrust that is so common a factor in stratal distortion; but if so, it has left but feeble evidence of its action.

The enormous thickness of the series is largely due to the extraordinary deluges of lava which were successively poured over the basin plain, molten deluges which have rarely, if ever, been surpassed in the course of known geological history. But we must not ignore the fact that twelve or fifteen thousand feet of detrital beds were interspersed

among or laid down over them. This detritus presents evidences of derivation by the usual agents of erosion and deposition. The igneous products doubtless greatly facilitated such derivation by affording material and conditions especially favorable for degradation and transportation. There may have been important contributions of ash and scoriæ, but we have found little clear evidence of this. The igneous action, we think, belonged to the class of massive fissure eruptions of Richthofen and not to the trivial Vesuvian type. But making such allowances for accelerating agencies as we are able, we are still impressed with the magnitude of the clastic series, and with the lapse of time requisite for its production, for the deposit of the last 12,000 feet took place after the lava floods ceased. This large conception of the time element is an important factor in our views. We have endeavored to fully recognize its magnitude, and at the same time, and for that very reason, to restrain ourselves from unnecessary assumptions that increase its extent. We have, therefore, inclined to those structural and genetic views which give sufficient latitude for these great processes and yet at the same time limit their magnitude to the least permissible measure. We incline to reject every view that unnecessarily magnifies the profound depth of the series, the vast lapse of time requisite for its production, the extraordinary amount of faulting necessary to its total displacement, or the inordinate strain of distension requisite to embody it in the midst of a trivial series.

We believe that the general horizontality of the Eastern Sandstone finds a perfectly simple explanation in the fact that it was laid down upon and against the Keweenawan, Huronian and Laurentian Series long after these had suffered their various upheavals, and that there has since been no considerable movement of the strata, except such crust oscillations as were common to the whole region. The sandstone has, therefore, remained essentially in its depositional attitude. Never having formed a part of the Keweenaw Series, nor having been in any close sense a partaker in its formative history, the discordance between the stratifications of the two series is precisely that which exists between the Potsdam and the other more ancient series of the region. Between the formation of the Eastern Sandstone and that of the Keweenaw Series, we think we find specific evidence of a great time gap.

We have previously indicated how, in our view, the Keweenawan sands were formed. Being derived from the upturned edges of the igneous series, they partook of the nature of the parent rock. The rim of the basin being at the time largely occupied by the extravasated igneous material, comparatively little drainage from the Archæan terranes beyond found access to the basin; hence the small percentage of material derived from other than Keweenawan sources. At the time of the formation of the Eastern Sandstone, on the contrary, there

had intervened a vast lapse of time, and the rim had been largely cut away in the production of the 12,000 feet of Keweenaw sandstones which overlie the lava flows. There had, furthermore, been a depression which had brought the sea again over portions of the Keweenaw Series that had previously been exposed to erosion, as its buried valleys and hills testify. These conditions greatly increased the drainage from the region beyond the Keweenawan borders and brought in a predominance of quartzose material from the surrounding Archæan terranes, very much as at the present day.

Furthermore, it is to be noted that a slow derivation of detritus from the decomposition of crystalline rocks would give an increased percentage of quartz, for, in a slow derivation, decomposition is a larger factor and a greater proportion of the silicates is disintegrated, little save the obdurate quartzose material being left intact to form sand. The degradation of the basin rim naturally slackened the rate of detrital derivation and increased the quartzose element. This it appears was somewhat felt in the closing Keweenawan deposition and serves to grade the two series toward each other. This is one of the considerations that renders uncertain the reference of the sandstones near the outlet of Portage Lake Canal.

The Eastern Sandstone must, however, in the nature of the case, have derived a portion of its material from the Keweenaw Series, and the element so derived we fully recognize; but its subordination to the quartzose element is no more to be neglected than its presence.

In thus widely separating the two series, we find our explanation of the diversity in their distribution and in their relations to each other. The phenomena about Lake Gogebic, where the Eastern Sandstone overlies the trappean series and extends itself through gaps in it, finds its explanation in the erosion of the interval and the unconformable deposition of the later series.

So also the diverse relations of these two series to topography finds its elucidation in the difference of age and the diversity of conditions under which the two series were formed. But this topic lies too largely without our special field and demands too great elaborateness of statement to be fittingly discussed here.

We find a very satisfactory explanation of the remarkable drainage features of the region in the view that the Potsdam Sandstone and the overlying Silurian deposits passed completely over the upturned edges of the Keweenaw Series and buried them beneath a sedimentary plain sloping toward the axis of the great basin. On the surface of this Paleozoic plain the drainage system first developed itself in entire neglect of the irregularities of contour of the buried Keweenaw Series below, and, having once established itself, cut its channels down irrespective of the relative resisting power of the terranes it encountered. It is a beauti-

ful instance of superimposed drainage, according to the classification of Gilbert.[1]

We shall again recur to some of the special conditions under which the Eastern Sandstone derived detritus from the Keweenaw Series.

The comparative straightness but gentle undulation of the junction line between the Keweenaw Series and the Eastern Sandstone is a point which bears rather upon the naturalness and rationality of our conceptions of the history of the region than upon their demonstrative character. It has not the direct logical bearing of some other features, but tests the several hypotheses mainly in respect to their appropriateness to the phenomena. We hold this long, gently curving line to be the result of ancient faulting, modified by subsequent erosion and by still more recent slight faulting. The earlier fault, in our view, antedates the deposition of the Eastern Sandstone. The erosion was probably in part contemporaneous with the faulting, in part intermediate between the faulting and the deposit of the Eastern Sandstone, and in part contemporaneous with and a part of the necessary work of the later epoch. The last faulting was posterior to the Potsdam epoch.

To be more precise in the statement of the time and of the amount of the first faulting is venturesome; and we hold no very firm convictions concerning its details, and yet certain considerations seem to justify a little light speculation upon the subject. Since the faulting was a factor in the crust movements of the region, we naturally connect it either with the final upheaval of the Keweenaw Series or with the subsidence which subsequently depressed the region beneath the Potsdam seas. We do not, of course, exclude the view of movement along the fault plane at both stages. On some accounts we incline to the view that it was a feature of the subsidence immediately antedating the Eastern (Potsdam) Sandstone deposition. If the Keweenaw peninsula had been elevated long anterior to its burial beneath the Potsdam and Silurian sediments, it would be rational to suppose that it would have been extensively dissected by erosion and would have presented a ragged line of hills or scattered knobs, instead of an almost unbroken ridge. It seems further probable that the Potsdam Sandstone would have been found more freely inserted in the valleys which the long erosion would have formed. From these considerations we draw a not very confident inference that the movement which elevated the Keweenaw peninsula or, as it may have been, depressed the basin now occupied by the Eastern Sandstone, was a movement that did not much antedate the Potsdam deposition, and was hence probably contemporaneous with the subsidence which brought again the seas into the basin. The little force of this presumption is mainly destroyed if we conceive the whole region to have been reduced to a base level of erosion and ascribe the relative prominence which the Keweenaw Series now has to the later faulting.

[1] Geology of the Henry Mountains, p. 144.

But this makes the later faulting more considerable than we would otherwise conceive it to be.

In so far as we have sought for a probable cause of the differential strain which gave rise to the fault, we have found most satisfaction in connecting it with the residual effects of the eruption of the preceding Keweenawan age. The areas in which the eruptive phenomena proper are most displayed, so far as we know, are the Marquette region, around which, as a kind of nucleus, the lake is bowed, and the northwestern shore of the lake in Minnesota and Canada. In both regions dikes are numerous and extensively intersect the crust. During the long process of eruption these regions felt the effects of the heat of the injected and extruded lavas, as well as the mechanical effects of the intrusion. An expanded condition was the natural consequence. This accords with the general truth that a state of progressive elevation, if not of intumescence, is a common accompaniment of volcanic action, whether due to this or some other cause. After the cessation of the igneous activity the temperature of the expanded mass doubtless slowly returned to the common temperature of the crust of the earth; and in the contraction which accompanied this may perhaps be found a cause, whether adequate or not, of the differential subsidence of these regions. Over against the Marquette region is the great Keweenaw fault, as we view it, and over against the other, the similar fault found in Douglas and Bayfield Counties, Wisconsin, and perhaps projected under the lake and along the north shore of Isle Royale, determining its prominence.

Under the view that a fault line runs along the face of the Keweenawan terrane, the correspondence between the present line of escarpment and junction line finds a ready explanation, since these are co-ordinate phenomena.

The disturbances along the contact line constitute the great sheet anchor of our convictions. The existence of these disturbances all along the line is now placed upon an unquestionable basis by direct observation. Nowhere have the formations been seen to come into close approach unattended by notable evidences of dislocation, and these, so far as we can ascertain, are closely confined to the contact line. These disturbances, we maintain, furnish unequivocal and decisive testimony. Along this line a movement has taken place which did not, in a similar disturbing way, affect the body of the formations on either hand. We have heretofore maintained that the evidence was such as to point convincingly to a faulting action. To that general evidence we have now added a large mass of new testimony of a very specific character.

In the fact that the Eastern Sandstone, at most observed points along the contact, is curved upwards, and in the manner in which this is done, we find evidence that the Keweenaw Series was elevated and

pushed against the Eastern Sandstone, or, reversing the conception, that the latter was depressed and underset. Whether the actual movement was made by the Keweenaw Series or by the sandstone, or whether both partook in an antagonistic motion, we do not know. From the fact that the former is a deep-seated, down-bowed formation in which any movement which tended to reduce its curvature would produce such an oblique thrust, we have preferred the first hypothesis. But this is quite immaterial. That a relative movement took place posterior to the formation of the Eastern Sandstone is, in our judgment, unequivocally demonstrated by the phenomena.

In the facts shown at the four sections in the vicinity of Torch Lake, we find a nearer approximation than elsewhere to a specific indication of the character of the faulting. In the absence of sufficient direct evidence, we have heretofore taken no account of a possible hade in the fault line, and, as yet, we know of no direct evidence touching the original fault line. It seems to us, however, most rational to assume that the earlier and later faulting occurred along a coincident plane. We entertain the view that a great line of weakness, once established, is likely to be selected by a subsequent differential strain. Observation, however, has taught that a later faulting does not necessarily follow the plane of an earlier one, even where its general course and position are essentially coincident with it, so that no very confident conclusions concerning the precise nature of the earlier fault can be entertained. Whatever may be true of the earlier fault in this case, the facts developed in the vicinity of Torch Lake in respect to the later movement seem to point clearly to a hade *from* the downthrow. The overhanging contacts in the Douglass Houghton and the Hungarian Ravines, the overturned dip in the Saint Louis Ravine, as well as the phenomena of offset in the Wall Ravine, all seem coincident with this view. As we interpret the phenomena, they testify to a movement of the Keweenaw Series upwards and slightly against the Eastern Sandstone, or, if you choose, a subsidence and underthrust of the latter.

Several special hypotheses may be framed to explain the precise facts which the phenomena, as now known, present. We select the following as being, on the whole, seemingly most closely in accord with the evidence:

In Figure 24 is represented diagramatically the nature of the primitive fault on the hypothesis that it was coincident with the plane of later faulting, as indicated by the contacts in the Torch Lake region. The amount of faulting movement we make no attempt to indicate. How great it was we have, as yet, found no means of determining. Our general hypothesis merely postulates that it was less than the total thickness of the series. Two general considerations limit our theoretical latitude. The greater the amount of the fault, the less the estimate of total thickness necessary to be made; and since that thickness, as exhibited in the exposed terrane, is already oppressively great, we feel

the less at liberty to unnecessarily add to the estimate of its magnitude, and therefore we incline to magnify the fault that we may minimize the thickness of the series. On the other hand, to magnify the fault is to multiply the amount of erosion which took place between its production and the burial of the series in the Potsdam epoch. While the testimony of adjacent regions indicates that the denudation of that interval was very great, we do not feel at liberty to so largely increase the estimate

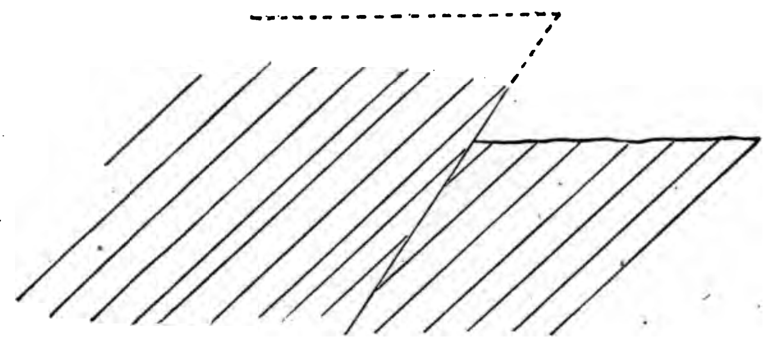

FIG. 24.—Ideal sketch of the primitive Keweenaw fault.

of its amount as to suppose a fault equal to the thickness of the upturned beds. A widespread denudation of several hundred or a few thousand feet we consider to be demonstrated, but the complete truncation of a mountain range several miles high we do not feel free to assume, even if there were no objections to supposing so great faulting. We are therefore checked in both directions, and have little doubt that the truth lies somewhere between the extremes in either direction.

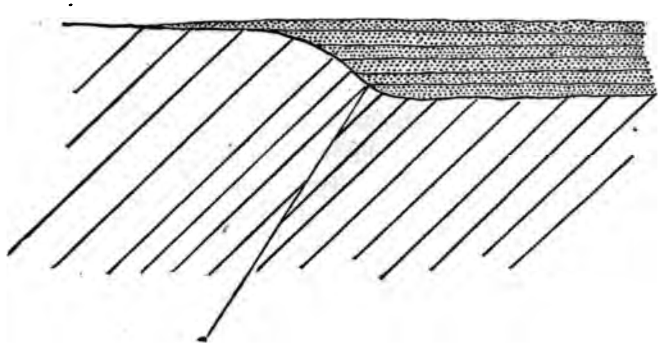

FIG. 25.—Ideal sketch of the Keweenaw fault, after the deposition of the Eastern Sandstone and before the secondary faulting.

Figure 25 is an ideal section across the fault line after the erosion of the crest of the upthrow and the deposition of the later strata against and upon it. It is clear that the brow of the upthrow would furnish favorable conditions for the derivation of pebbles and bowlders from the Keweenaw Series and that the shore line would be suitable for the

accumulation of "mud and shingle" deposits; in other words, under these conditions, the derivation of the pebbles of the Eastern Sandstone is satisfactorily elucidated.

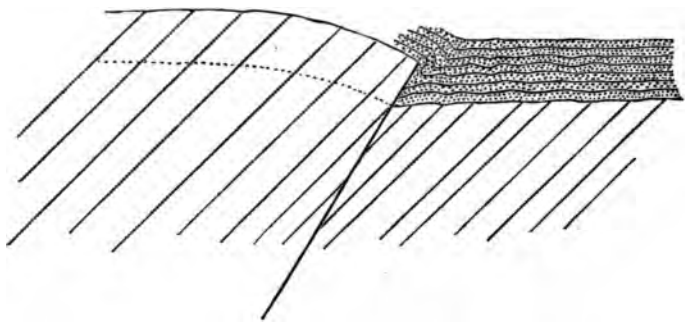

FIG. 26.—Ideal sketch of the Keweenaw fault, after the secondary faulting.

Figure 26 represents the supposed result of a further slight faulting along the old line. The Keweenaw beds on the upthrow side are pushed obliquely upward and against the Eastern Sandstone. The general effect was to upturn the sandstone and bow it into undulations for a moderate distance adjacent to the fault line, beyond which it remains undisturbed. We conceive that on account of the inclination of the upthrust (or downthrow, as it may have been) some beds at the immediate contact line were bent under while the majority were turned upward. The action was like the pushing of a blunt wedge obliquely into the edges of the sandstone strata. The one result is the expression of the element of upward thrust and the other of the lateral push. We conceive, also, that, on account of the oblique thrust, there would be a faulting movement along the line of unconformable contact on the sloping brow of the Keweenawan uplift. Now, since decomposition of the Keweenawan beds along this line of contact had probably greatly softened the edges of the trappean beds, in accordance with the general law of contact decomposition, comparatively little force and motion were necessary to reduce the already softened material to the condition in which we find the junction débris.

In those instances in which the pre-Potsdam erosion had produced slight valleys or embayments along the face of the old Keweenawan uplift, the later movement would naturally have the effect of pushing the beds up into a curved sinuous rim.

Now, if denudation be conceived to have since cut the disturbed beds down to different depths, the several sections which we have heretofore constructed in a purely empirical manner, on the basis of observation, may find elucidation in the rational results involved in this hypothesis. The truncating of the curved rim formed by the turning up of the embayed beds of the sandstone along the junction would display such sinuous margins as constitute the beautiful phenomena of Bête Grise

Bay. In cases where the erosion progressed so far as to cut away entirely the overlapping beds of sandstone, the various phenomena of the overthrust would be displayed. Such upturned beds as those of the Wall, Saint Louis and Douglass Houghton Ravines illustrate one phase of the action, while the down-bent beds of the Douglass Houghton and Hungarian ravines exemplify another phase. We conceive that both the overlying and the underlying contacts, as well as the upturning and downturning of the sandstone strata, may be the results of a simple oblique thrust of the wedge-like edge of the uplifted Keweenawan strata.

Similar results, however, might be produced, whatever the hade of the original fault, if it be assumed that some individual movement of the Keweenawan beds on each other took place during the last faulting. That faulting may be distributed along several planes that offer comparatively small shearing resistance is affirmed by theoretical considerations, experimentation and observation in nature. We have, at times, been inclined to believe that the post-Potsdam disturbance was due to a slight irregular movement of this kind, but the increased evidence now at command seems to strengthen the probability that there was a definite, and not inconsiderable, faulting movement somewhat of the kind above indicated.

To us the nature of the contacts, at the several points where they were revealed by excavation, seems to strongly corroborate, if not absolutely demonstrate, the correctness of our views. We are unable to form any satisfactory conception of the precise method in which the junction débris—consisting of trappean fragments and comminuted trap, mingled with joint clay and sand from the Eastern Sandstone, the whole reduced to a foliated structure, though still very soft, and marked by slickensides—could be produced, unless it be the product of a faulting movement. Nor are we able otherwise to find a satisfactory explanation of the imperfect basal face of the overhanging trap, on the one hand, or of the bent and truncated face of the sandstone on the other. The contact is clearly not that of a shore cliff, for its characteristics are markedly diverse from that. It is to us equally clear that it is not a contact of depositional superposition, for it is devoid of the stratigraphic conformity and of the structural characteristics which belong to such a relation. The contact faces furnish, as we think, specific evidence of faulting movement.

Not only do we appeal to the nature of the contact and the contact débris, but to the fact that different members of the two series come into conjunction. Along Bête Grise Bay the contact of the Eastern Sandstone is made with different members of the Keweenaw Series, as specifically pointed out above. All these members belong to the base of the Bohemian Range and are relatively low in the series. In the Torch Lake region, several distinct members are shown in contact; but all be-

long to a considerably higher horizon than those of Bête Grise Bay. At Wall Ravine the junction is made with a porphyritic conglomerate; in the Saint Louis Ravine with diabase, lying not far below the thin Saint Louis conglomerate bed. In the Douglass Houghton Ravine, the junction is made with a broken diabase. In the Hungarian Ravine the contact is with diabase immediately underlying a thick conglomerate bed. In no two of the above localities does the Eastern Sandstone come in contact with the same member of the Keweenaw Series. While the junction line approaches the strike of the beds, it nevertheless crosses it at a small angle and continually brings into contact different members.

So, on the other hand, different horizons of the Eastern Sandstone come into junction with the Keweenaw Series at different points. The beds at Bête Grise Bay are the peculiar soft breccia shales. In the Wall Ravine they are of sandstone, several hundred feet below the most conglomeratic horizon. In the Saint Louis Ravine they are sandstone, likewise below the conglomeratic horizons. In the Douglass Houghton they are sandstone, shales and the conglomeratic horizons themselves. In the Hungarian Ravine the contact beds are sandstones that appear to be considerably above the most conglomeratic beds. It is not absolutely certain that the conglomeratic beds in the last four localities are the same. But there is a general correspondence in their characters, and it seems not improbable that the conglomeratic beds of the four localities are essentially identical; but whether this be so or not, it is clear that beds of quite different characters and stratigraphical relations appear in contact at the several points. Now we esteem this altogether fatal to a view that makes the Eastern Sandstone a conformable basal member of the Keweenaw Series. It is not necessarily fatal to views which postulate faulting other than that which we advocate nor to views which assume the escarpment to be an old erosion cliff.

Of like import to the above is the discordance in the strike of the two series near the junction. The strike of the sandstone series was partly determined by the form of the basin in which it was deposited and partly by the tilting to which it was afterward subjected. The fault line and the agencies associated with it were chiefly influential, in our view, in determining both of these factors, and as that fault line was not strictly concordant with the strike of the Keweenawan beds and as the strikes of the Eastern Sandstone were not strictly in concord with the fault line, a very considerable discordance between the strikes of the two series was the result. At the same time there were no very large departures from each other. The angles between the strikes, in the cases examined by us, were mainly less than 45°.

Passing to the Eastern Sandstone, we find in its pebbles evidence of a significant character. We hold that the appeal of Agassiz and Pumpelly to the evidence presented by the existence of these trap-

derived pebbles is fully sustained and is greatly emphasized by the additional facts we now present. That the Keweenawan beds must have been exposed to shore action and drainage erosion at the time of the deposition of the Eastern Sandstone seems to be a necessary conclusion from the facts. These pebbles, as we have fully specified above, are derived from no single Keweenawan bed, but, variously, from the several members of the complex terrane. There are all the leading varieties found in the adjacent trappean series, but found nowhere else in similar assortment and kind. There is no other conceivable source within the range of known facts.

Their mere existence, however, does not demonstrate that the Eastern Sandstone belongs to any other category than the sandstones and conglomerates of the Keweenaw Series, but we think that the specific facts relating to their character and distribution do constitute such a demonstration.

In support of this claim we appeal to the abundance of trap-derived pebbles near the junction line and to their rarity, so far as we know, at any considerable distance from it. The Eastern Sandstone is quite extensively displayed along the borders of Keweenaw Bay, at distances not greatly removed from the Keweenaw Series, and yet nowhere have we found it, or are we aware that others have found it, characterized by the pebbles in question. Furthermore, in the several ravines in the vicinity of Torch Lake, at distances a mile away from the junction line, pebbles are relatively rare. It is true that this may be in part due to the horizons which there chance to be exposed, and it may be true that some of the conglomeratic beds extend much farther back from the junction line. But we made some specific observations that show a definite disposition on the part of the pebbles to increase in number and size toward of the contact line, and we believe these observations to be representative of the general fact.

We also appeal to the imperfect assortment of the material of the conglomerates. If the material had been of distant derivation and had been rolled to and fro for long distances, the assorting action incident to such transportation must have been of a high order, and the definite association of material of definite degrees of coarseness such as is common to the great widely-distributed conglomerates would probably have resulted. But, on the contrary, as previously described by Agassiz and fully supplemented by our own observations, the deposit is of that peculiar type happily styled "mud and shingle" deposit, which signifies a limited action on the part of the assorting agencies. We follow Agassiz in believing this to surely indicate a proximity of the shore line whence the pebbles were derived.

We appeal, furthermore, to the angularity of the pebbles in the exposures at Bête Grise Bay. This is a very notable feature. The

amount of wear which the pebbles have suffered, while noticeable, is very limited, and the result is a breccia rather than a pudding-stone. It seems to us quite impossible that the material of this deposit was derived from any distant source. But in the sections near Torch Lake, the angularity is not a notable feature, and a somewhat more distant derivation is indicated or else a larger measure of sub-aërial rounding of the fragments before they were brought within reach of the depositing waves.

Concurrent with this measurable rounding of the pebbles is the absence of great fallen cliff masses and of exceedingly large bowlders. From the absence of these, at the contact, we infer the absence of beetling cliffs from which such masses would inevitably have been thrown down and buried. This is another form of saying that after the first great faulting, and previous to the incursion of the Potsdam shore line, there had been sufficient erosion to cut away the great fault cliff and reduce the surface contours to moderate slopes. Against these moderate slopes we conceive the sandstone to have been deposited, and, from their declivities, the constituent pebbles to have been derived.

Larger observation may modify the special phases of the conception to be derived from these details of the structure of the border belt, but, in the formation of our opinions concerning these particulars, we have endeavored to follow the legitimate conclusions to which the phenomena seem to point.

The occurrence of Trenton Limestone, capping a hill which reposes centrally upon the tract of Eastern Sandstone, leaves us no choice but to regard the latter as Potsdam, and, in this one conclusion, at least, we are fortunately in harmony with all our fellow-students. The existence of Silurian limestone at this point seems to indicate that it once spread extensively over the Lake Superior basin. From the fact that in the vicinity of Torch Lake the Eastern Sandstone rises to near the crest of the peninsular ridge, and near Houghton is thought to be represented by a remnant actually overlying it, we infer that the Silurian limestone may have been originally deposited over the peninsula. It is quite possible also, that later formations once overlay this. Under such conditions, the origin of those streams which cross the peninsula is easily understood, as heretofore remarked.

SUMMARY.

Recapitulated, the history of events, as we read them, was essentially as follows: The Keweenaw Series very greatly antedated in its formation the Potsdam Sandstone, and occupied a lapse of time immensely vaster than the Potsdam as that formation is known in its unquestionable localities east or west. It was a period characterized by

some of the most remarkable displays of igneous activity of which the world has been a witness. Accompanying and succeeding this, were orographic movements of a protracted, though apparently gentle, character. These were succeeded by a long interval of erosion, unbridged, so far as we can see, by any known deposit in the Lake Superior basin. Indeed, the very conditions which made the erosion possible forbade depositions which would now be accessible. At an undetermined time before the close of this erosion, a longitudinal fault line was developed along what is now the face of the trappean terrane of Keweenaw Peninsula. Subsequently, submergence beneath the Potsdam seas ensued, and the Eastern Sandstone was laid down unconformably against and upon the Keweenaw Series. Upon this the Trenton Limestone, and possibly other members of the Silurian series, accumulated conformably. At a later stage these were removed by secular erosion, and, at some time not more definitely determined than that it was post-Potsdam, a minor fault movement along, or near, the old break took place, by which the beds of the Eastern Sandstone were disturbed along the contact, and various faulting phenomena developed.

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